Necessarily, salt dissolves in water

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1. Introduction

In this paper I aim to show that a certain law of nature, namely that common salt (sodium chloride) dissolves in water, is metaphysically necessary. The importance of this result is that it conflicts with a widely shared intuition that the laws of nature (most if not all) are contingent. There have been debates over whether some laws, such as Newton's second law, might be definitional of their key terms and hence necessary. But the law that salt dissolves in water is not that kind of law. The law statement 'salt dissolves in water' is clearly synthetic. It appears a classic case of a contingent law. We like to believe that there are possible worlds in which the laws of nature are different and in which salt does not dissolve in water.

Showing that our intuition about the contingency of this law is mistaken reinforces two lessons of Kripke's well-known arguments concerning necessity and identity: that our untutored intuitions concerning modal status are unreliable and that there is more necessity around than we might think (Kripke 1980). The result has further significance also. Dispositional essentialists (dispositionalists, for short) about properties are committed to regarding the laws of nature as metaphysically necessary – they are necessitarians about laws.[1] Their critics, who are categoricalists about properties and contingentists about laws, regard this as a major disadvantage, as conflicting with a deep intuition that laws are mostly contingent. If it can be shown, independently of dispositionalism, that some apparently contingent laws are in fact necessary, then this objection loses its force.

The premisses of the argument I present should be acceptable to contingentists. It assumes that the basic laws of nature are contingent. It then shows that some laws that supervene on the basic ones will not themselves be contingent. One lesson for contingentists is that they cannot be contingentist about *all* laws, not even all synthetic, a posteriori laws. Overall, the argument may be seen as a disjunctive dilemma. Either the basic laws are necessary, in which case those that supervene on them are necessary; or the

[1] See Mumford 1998: 216–17, 236–37, and Ellis and Lierse 1994 for discussions concerning the relationship between dispositionalism about properties and necessitarianism about laws.

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basic laws are contingent, in which case my argument shows that some important laws that supervene on them (such as that salt dissolves in water) are necessary nonetheless. Either way, some important laws are necessary. Clearly it is the second horn of the dilemma that is contentious. But the argument is straightforward. A law like 'salt dissolves in water' says that two substances interact in a certain way. That interaction is brought about by an underlying law, C. For it to be contingent that salt dissolves in water there must be a world in which salt and water exist but the latter fails to dissolve the former. Hence C must be false. But the existence of substances depends on laws. And it turns out that the existence of salt and water requires, necessarily, the truth of C. So, after all, there is no world where salt and water exist but the latter does not dissolve the former. Hence necessarily salt dissolves in water.[2]

2. *Some simple (and only slightly simplified) chemistry*

Common salt, sodium chloride in its solid form, is an ionic crystal. The sodium atoms exist as positively charged sodium ions, while the chlorine atoms exist as negatively charged chlorine ions. These ions are arranged in a face-centred cubic lattice, with chlorine and sodium ions alternating. The lattice is held together by the electrostatic attraction between the ions. Each positively charged sodium ion is neighboured by six negatively charged chlorine ions, and vice versa. The magnitude of electrostatic attraction is governed by Coulomb's law. The structure of water is explained somewhat differently. Water exists as covalently bonded molecules. Each water molecule contains one oxygen atom and two hydrogen atoms. Each hydrogen atom shares a pair of electrons with the oxygen atom, allowing the stable completion of the outer shells of all three atoms. The details of this are explained by the laws of quantum mechanics. What makes water a liquid at normal temperatures and pressures? Electrostatic attraction comes in here again. The laws of quantum mechanics that govern the bonds in a water molecule also determine the shape of that molecule. The hydrogen atoms are not in a straight line but form a dog-leg, at an angle of 105°. On the dog-leg side of the molecule there is a slight positive charge while on the other side there is a negative charge. The molecule is thus electrostatically asymmetrical and is known as a *dipole*. At normal tempera-

[2] For convenience, I am assuming that a world in which there is either no salt or no water is one in which it is trivially true that salt dissolves in water. Some readers may not like this. In which case I am happy to restrict the sort of necessity I am discussing to the necessity that Kripke ascribes to identity: Eric Blair is George Orwell is necessarily true in that, in all worlds in which Eric Blair (or George Orwell) exists, Eric Blair = George Orwell. This is compatible with there being some worlds where there is no Eric Blair (or George Orwell).

tures and pressures, the electrostatic attraction between the positive and negative parts of the dipoles is enough to keep them together as a liquid.

It is the polar nature of the molecules that make up water that enables it to dissolve sodium chloride. The electric potential energy of sodium and chloride ions surrounded by the water dipoles is less than the electric potential energy of the sodium chloride crystal and the pure water separately (Gray and Haight 1967: 452–53). In causal terms, the force of electrostatic attraction exerted by the water dipoles on a sodium atom on the surface of a salt crystal is less than the electrostatic attraction exerted on that atom by the remainder of the salt crystal. It is thus pulled away from the crystal and into solution. For the purposes of this paper, the important thing to note about the process of dissolving is that it is entirely electrostatic in character. The force of electrostatic attraction between ions and dipoles, as between any charged objects, is just the force governed by Coulomb's law. Hence if there were a world in which salt failed to dissolve in water, that would have to be a world in which Coulomb's law is false.

It will be pointed out that in the preceding paragraph I have ignored the contribution of Newton's second law (or whatever corresponds to that law in reality). Coulomb's law supplies the forces, but Newton's law is required to determine how the molecules and ions behave when subjected to those forces. So perhaps there could be a world in which there was a failure to dissolve because Newton's law is false even though Coulomb's law is true. It makes my argument more perspicuous to deal with this point later, and to ignore the role of Newton's law until then. Alternatively, it is possible to read the argument as presented below, when it talks of 'Coulomb's law', as referring to a *conjunction* of Coulomb's law and Newton's law. This combined law describes the motions of charged bodies when subjected to no other forces. Since no other forces play a relevant part in the discussion – salt dissolves in water in weightless conditions – we may take it that this law is in operation.

3. *The argument*

The argument proceeds by *reductio*. Assume that it is contingent that salt dissolves in water. Then there is a world in which salt, when placed in water, does not dissolve. (As we have seen, in such a world Coulomb's law is false.)

The bulk of the argument shows that the existence of substances can necessitate the existence of certain laws. If those laws did not hold, then the substances could not exist. Hence in worlds where those substances do exist, those laws hold also. In particular the existence of salt necessitates the truth of Coulomb's law.

Kripke's and Putnam's arguments show that the fact that water is *composed* of hydrogen and oxygen and the fact that salt is *composed* of sodium and chlorine are necessary facts. The same arguments show that the *structures* of water and salt are also essential. For a mixture of hydrogen and oxygen is not water, in this or any other world. That water is a *compound* comprised of *molecules* of hydrogen and oxygen is essential to water. The notions of 'compound' and 'molecule' are structural notions. And we can say more, that the precise molecular structure of water is essential to it, since water is not the same as hydrogen peroxide, also a compound of hydrogen and oxygen, but one with the formula H_2O_2 – its molecules have two oxygen atoms unlike water's one. Furthermore, not even the numbers of atoms in a molecule are sufficient for identity of substance. Isomers are substances that possess the same formulae but are different substances nonetheless. That is because the constituent elements, although the same for both substances, are arranged differently in their molecules. Allotropes provide examples of elements that exist in different forms, which in some cases amount to different substances, such as diamond and graphite, due to structural differences.

That structural properties are essential is not limited to chemical substances. The painting known as the *Mona Lisa* would not be the same painting were its molecules of oil and pigment arranged significantly differently. But what is important about the chemicals is that their structure is not a matter merely of spatial arrangement. What makes a water molecule a *molecule* is not merely that there is an oxygen atom neighboured by two hydrogen atoms, but that these neighbouring atoms are chemically bonded to one another in a certain way. So the chemical bonding found in water is an essential feature of it, and any world in which there is water is a world in which there exists that kind of bonding.

Similar remarks may be made about the structure and the chemical bonding of salt. These properties are likewise essential. In the case of salt, as we have seen, the bonding is not, like water, covalent but is instead ionic. I do not think it possible that there could be a world in which sodium and chlorine bond covalently. But even if there were, the resulting compound would not be salt. Such a compound would have properties completely unlike salt.[3] Thus the ionic character of salt is essential – any world in which there is salt is a world in which there exists an ionic bond. An ionic bond is, by definition, a bond that exists in virtue of the electrostatic attraction between ions. And electrostatic attraction is, necessarily, the force that

[3] For example, a covalent compound would have a low melting point and would not conduct electricity in its molten state or in solution. It would be a solvent for and be soluble in different substances.

exists between charged objects in virtue of Coulomb's law. Hence a world in which there is salt is a world in which Coulomb's law is true.[4]

The argument has shown so far that a world in which salt exists is a world in which Coulomb's law holds. That includes, therefore, the world we are supposing to exist, where salt and water exist but the former fails to dissolve in the latter. However, at the end of the previous section we saw that a world in which there is a failing of dissolving is one in which Coulomb's law is false. So this world is one in which Coulomb's law is both true and false. Hence there is no such world, and the assumption that it is contingent that salt dissolves in water is refuted.

4. *Quibbles*

In this section I briefly present three possible concerns and show how they may be accommodated.

First, I need to deal with the fact that Coulomb's law needs supplementation by Newton's second law in order to have implications for the motions of bodies and hence to ensure that salt dissolves in water. So Coulomb's law is not strictly sufficient for dissolving. The fact that the argument works for the combined law shows how to deal with this concern. The crucial part of the argument is that the existence of salt requires the truth of Coulomb's law. But, as is apparent, it requires the truth of Newton's second law too. For if that law were false, and two bodies subjected to forces directed towards each other were not to accelerate towards one another, then despite the forces between the ions in a salt crystal these would not hold together as a substance. So the existence of crystalline salt is enough to entail the truth of *both* Coulomb's law and Newton's second law, and these together are sufficient for ensuring that salt will dissolve in water.

Secondly, does the existence of an ionic compound really require Coulomb's law? Perhaps some law quite similar to Coulomb's law would allow the existence of recognizably electrostatic forces and hence of ionic compounds. For example, Coulomb's law has a form like that of Newton's law of gravitation: $F = -\varepsilon_0(pq/r^2)$ where ε_0 is a constant and F is the force between two charges whose values are p and q and whose separation is r. If ε_0 took a different value then we would have a different law. But the new

[4] Since water is covalently bonded, this argument will not appear to apply to water as well. However, no covalent bond is purely covalent, and each has an ionic character too. In the case of the O-H bond this is estimated to be 39% (Pauling 1940: 78). It is unclear whether this partial ionic character and its consequences are essential to something's being a water molecule. If so, that is a reason why the existence of water, as well as the existence of salt, entails the truth of Coulomb's law.

law may be sufficiently similar to the old one to produce very similar behaviour among charged objects and so accommodate the existence of salt and liquid water. So we have salt and water without Coulomb's law.

Be that as it may, it does not undermine my argument. For a law that supports something very like the electrostatic behaviour of charged objects (as it occurs in this world) is a law that will ensure that something very like dissolving (as it occurs in this world) takes place. This consideration allows us to see that the argument presented here has a high degree of generality. It is not just a rarity concerning water, salt, and dissolving. Let L be a high level law concerning a set of substances, S. For reasons mentioned above in footnote 2, we can regard L as trivially true if any of substances S do not exist:

(1) ⟨the substances S do not all exist⟩ *entails* L.

The existence of substances requires the existence of some laws. But perhaps different sets of laws might do the job of generating those substances. Let C_1, C_2, C_3, … be the different sets of laws that would each allow the existence of S. So a world in which the substances S exist is a world in which one of C_1, C_2, C_3, … is true:

(2) ⟨the substances S exist⟩ *entails* $C_1 \vee C_2 \vee C_3 \vee \ldots$

The law L itself will also depend on laws more basic than L. In the actual world L may depend on a subset of C_1 – so C_1 is sufficient for the truth of L. This dependence is metaphysical, and in some cases even logical. The higher level law may be deducible from C_1. But even if not, L will supervene on C_1. It may also be the case that each of C_1, C_2, C_3, … is sufficient, in this sense, to ensure that L is true:

(3_1) C_1 *entails* L
(3_2) C_2 *entails* L
(3_3) C_3 *entails* L

and so on for all the C_i in the disjunction in (2).

(2) and all the (3_i) together entail:

(4) ⟨the substances S exist⟩ *entails* L.

That is, any world in which there are laws that enable S to exist will be a world in which those same laws ensure that L is true.

(4) and (1) give us:

⟨the substances S do not all exist⟩ ∨ ⟨the substances S exist⟩ *entails* L.

Since the antecedent is a logical truth, L is necessarily true.

Such a case will arise when each of the sets of laws C_1, C_2, C_3, … ensures that L is true. Is that likely to be a frequent occurrence? I suggest it is. The sets C_1, C_2, C_3, … are those laws that allow the substances S to exist. And as the discussion surrounding variants on Coulomb's law indicated, the sets C_1, C_2, C_3, ... will be close relatives of one another, differing only in details of degree (such as the values of fundamental constants), not in kind. As argued, different *kinds* of law responsible for the existence of a substance generate different substances. In short, for a law L relating substances S to be necessary, the sensitivity of the existence of all the substances S to changes in underlying laws needs to be greater than the sensitivity of the truth of L to those changes. Note that this situation is likely to be ubiquitous if the world is governed by a few very simple fundamental laws (as appears plausible). For then all the fundamental laws will be implicated in the existence of all substances and higher level laws. Any differences in fundamental laws would entail a world quite unlike ours as regards both substances and laws. The existence of substances (that exist in our world) then entails the truth of the laws that relate them. Another direction in which the argument can be generalized concerns laws that relate properties rather than substances. The argument may be just run again with the instantiation of properties taking the place of the existence of substances.

The third concern is that most, perhaps all, laws are *ceteris paribus* laws. So, strictly, the actual world is not a world in which salt always dissolves in water. It does not dissolve in water in which salt or other electrolytes are already dissolved in high concentrations. Although Coulomb's law is true, something (perhaps like Maxwell's demon) might interfere with the molecular processes to counteract that law. To respond to this concern we need to be careful how we conceive of *ceteris paribus* laws. On the one hand we might conceive of them as generics that have admissible exceptions. Thus 'birds have two legs' has exceptions – birds that have lost a leg in an accident. But the exceptions are still within the scope of the law. One-legged birds are still genuine birds. On this view the generics that are laws are not equivalent to nor even entail the corresponding generalizations: 'birds have two legs' is true even though '*all* birds have two legs' is false.

The latter conception of *ceteris paribus* laws might have some difficulty in straightforwardly accommodating my argument (although I think it can, with appropriate adjustments). But a different conception does not have any difficulty. This conception says that laws do entail true, exceptionless generalizations, but those generalizations cannot be expressed without use of something like a *ceteris paribus* clause. The requirement for *ceteris paribus* clauses has been a philosophical problem when we are looking for *analyses* of concepts (e.g. the analysis of dispositional concepts in terms of conditionals). But there is no reason why it should be an obstacle to metaphysics. There is some nomic fact identified by chemists when they state that salt dissolves in water (call that fact 'F'), even if that fact is not identical to the (non-existent) fact that salt always dissolves in water (call this one 'G'). My argument, which can be run again with *ceteris paribus* clauses included, establishes that F is necessarily the case, even if G is not even contingently the case.

5. *Conclusion*

I believe I have shown that a law that looks contingent is in fact necessary. The argument is consistent with taking the fundamental laws to be contingent – we treated Coulomb's law as contingent. No question is begged against someone who is a contingentist about fundamental laws, and similarly no question is begged against the categoricalist about properties. What it does mean is that contingentists and categoricalists must not be too quick to employ our intuition that the laws of nature are contingent against the necessitarians and dispositionalists. The intuition is an unreliable one. Perhaps the contingentist thinks that there are other laws that are more clearly contingent than the law that salt dissolves in water. Perhaps the values of fundamental constants are nomic facts that are obviously contingent. Even so, contingentists should be wary. The necessity of salt dissolving in water was revealed by a posteriori facts of chemistry. Discoveries in physics may reveal that what seemed to be contingent facts concerning the values of constants turn out to be necessary. We do not even know that there are any fundamental constants and leading physicists speculate that there may be none. (See, for example, Weinberg 1993: 189.) The debate between categoricalists and dispositionalists about properties and contigentists and necessitarians about laws needs to proceed without uncritical reliance on modal intuitions.[5]

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