THE STRUCTURE AND NECESSITY OF THE NATURAL LAWS

Abstract

In this paper I consider the structural relations among the laws of nature. I show that under some circumstances such relations can have the consequence that some non-fundamental laws are necessary even if the more fundamental ones are contingent. Generalizing my earlier work in this question, I give a precise account of such circumstances.

1 Introduction

Metaphysicians and philosophers of science have given considerable thought to the question, What is a law of nature? But they have given rather less thought to the question, What is the structure of the laws of nature? In posing and responding to this question I intend to focus on the structural relationships between laws of nature, in particular the relationship between fundamental and non-fundamental laws. It is not that there has been *no* thought at all. The relationship between observational laws and theoretical laws and the status of bridge laws were questions of this kind, posed within an empiricist framework. Another area of study has been the question whether non-fundamental laws, e.g. the laws of chemistry or biology, such as they are, are reducible to the laws of physics. The first of these lost its relevance with the demise of empiricism. And research on the second seems not to have progressed beyond the issue in question. For example, among those who reject reductionism but accept some thesis of supervenience, it seems to have been assumed that there is little more to be said about the structural relationship between the fundamental and non-fundamental laws, as if to say more would be to return to reductionism.

In this paper I shall show that there is more that can be said about how non-fundamental laws supervene on the fundamental ones, without implying reductionism, and that these structural relationships have important consequences concerning the modality of laws.

2 A simple reductionist model

A simple model of the structure of laws is this. Assume that the fundamental laws are all universal generalizations. The non-fundamental laws are deductive consequences of these laws. Let there be a world with two fundamental laws:

(A) $\forall x(Fx \to Gx)$
(B) $\forall x(Gx \to Hx)$

Here the derived, non-fundamental law of interest will be:

(C) $\forall x(Fx \to Hx)$

(Other derived laws will include the contrapositive logical equivalents of the fundamental laws.)

It seems to be a common assumption that if the fundamental laws are contingent, then the derived laws will also be contingent. This might be an important part of the widespread intuition that the laws of nature are *all* contingent. Take any non-fundamental law. Why should be think that it is contingent? One reason might be that such laws are discovered *a posteriori*. But after Kripke we know that this is a poor reason for taking a proposition to be contingent. Another reason might be this. The fundamental laws we may take to be contingent, since they are matters of brute fact that might have been otherwise. The non-fundamental laws, being derived from the fundamental ones are thus also contingent. But the mere fact that it is a consequence of contingent fundamental laws is not a reason for supposing the non-fundamental law to be necessary, for, trivially, any proposition (contingent or otherwise) entails every necessary proposition. Nonetheless, it seems to be assumed, non-trivial consequences of contingent propositions, such as (C), will also be contingent, even though there is no good reason for thinking that such an assumption is true, as well as good reasons for thinking that it is false.

David Lewis's systematic regularity theory of laws comes close to the simple model. For Lewis a regularity is a law if and only if it appears as an axiom or theorem in that true deductive system which achieves a best combination of strength and simplicity. Although Lewis does not assert that every law is contingent, it is clear from his account of counterfactuals that he regards the typical non-fundamental law as unproblematically contingent. (Since the truth of counterfactuals requires worlds like the actual one but which have minor deviations from the actual laws.) And by taking non-fundamental laws to be *deductive* consequences of the fundamental ones, Lewis's view conforms to the simple model.

Even Lewis' model cannot guarantee the contingency of derived laws. Considering (A) and (B), if F=H then both may be contingent while their consequence (C) is a logical truth. There are other cases where (C) is a non-logical necessary truth. Let Fx = x is comprised of water, Gx = x is comprised of the main constituent of living things on Earth, Hx = x is comprised of H_2O, then (A) and (B) will be contingent while (C) is necessary, and all three will be non-logical truths known *a posteriori*.

In any case, the simple model, including Lewis' version, will not do. It states that non-fundamental laws are *deductive* consequences of the fundamental laws. In which case all non-fundamental laws will have as relata terms that appear in the fundamental laws (such as the F and H in (C)) or which can be defined in such terms. But that is clearly false; there are laws concerning water, but water is not a relatum in any fundamental law nor is 'x is water' definable in terms of the relata of fundamental laws.

What should replace the simple model? And in the absence of an obvious replacement, should we be confident that the non-fundamental laws are contingent? The grounds the model gave for thinking that they are contingent were themselves weak. But if we reject the model and so do not have a view about the structural relationship between the fundamental laws and the non-fundamental laws (while also being ignorant of what the fundamental laws themselves actually are), then it seems that we are in a very weak position to assert that the laws of nature are contingent. In what follows I shall start to fill in part of the picture of the relationship in question. And as we shall see, at least some of the non-fundamental laws will be necessary, possibly all of them.

3 A more sophisticated model

An improvement on the simple model must recognise that non-fundamental laws relate properties and kinds that are not involved in the fundamental laws. Take the property of being comprised of water. This property and the non-fundamental laws it engages in will depend on the fundamental laws in two ways.

First, given the existence of water, the laws it engages in will supervene on the fundamental laws. For example, water will engage in certain chemical reactions with other substances. That water engages in these reactions is a non-deductive consequence of the electrical and quantum properties of the molecules of water and their constituents. The relevant laws can be thought of as operating is something like the manner suggested by the simple model. When a volume of water reacts with a lump of potassium, we can think of the outcome as the consequence of billions of microphysical interactions governed by the relevant microphysical laws. Ultimately, the laws at work are really the fundamental laws. Even though we may not be able to deduce the reaction laws from the fundamental ones, it is nonetheless easy to conceive of the reaction law being a consequence of the fundamental law operating in some massively parallel process on the myriad of fundamental entities that compose the water and the potassium. However we conceive of this process, it is nonetheless accepted that the non-fundamental law is entailed by the fundamental laws. Let us call the conjunction of the fundamental laws F, and the non-fundamental law N. Then we have:

(I) F entails N

There is a second way in which the fundamental laws enter into the non-fundamental law. We noted that the relata of the non-fundamental law are not themselves relata in the fundamental laws. These relata we may call non-fundamental properties and kinds. So in accounting for the relationship between fundamental and non-fundamental laws we need to ask about the relationship between the fundamental laws and the non-fundamental properties and kinds. The most obvious thought is that the fact that there can be water or any other non-fundamental substance is itself a consequence of fundamental laws. The laws of quantum mechanics are consequences of the fundamental laws and the possibility of hydrogen and oxygen combining to form H_2O is a consequence of the laws of quantum mechanics. (Here the possibility is nomic possibility.) So far matters are no so different from the above. Let S be a non-fundamental substance. Then we have:

(II) F entails the possibility of S.

However, matters are more subtle than this. Imagine that the possibility of S is highly sensitive to variation in the laws of nature; that is slight changes to intermediate level laws would not permit the existence of S. For example, it may be that slight changes to the laws of quantum mechanics would not permit the existence of water (hydrogen and oxygen would not bond); or slight differences in the laws of biochemistry would not permit the formation of DNA and so human beings would not exist. Further suppose that the intermediate level laws themselves are highly sensitive to the fundamental laws, so that if the fundamental laws were other than they actually are, in any degree, then the intermediate laws would not hold. Let us call this set of suppositions the *super-sensitivity* of substances to fundamental laws (just *super-sensitivity* for short). (I shall address the question, whether super-sensitivity ever arises shortly.) If super-sensitivity holds for S with respect to a fundamental law F, then:

(III) Necessarily, if F is false, then S could not exist.

The ‘necessarily’ is metaphysical necessity whereas the ‘could’ is nomic possibility. That is (III) asserts that in no possible world do the laws, if they lack F, nomically permit there be S. So (III) in turn yields:

(IV) The existence of S entails F.

We have seen two kinds of relationship between non-fundamental laws and the properties, kinds or substances they given and the fundamental laws. Let us now combine these two kinds of relationship. (IV) and (I) give us:

(V) The existence of S entails N.

Note that N is *any* non-fundamental law. So, in particular N might be a law involving the substance S. Let N be the law that everything that is S is T. So we have:

(VI) The existence of S entails that everything that is S is T.

Consider what would be required for N to be false. Something would have to be S that is not T. But (VI) tells us that in all worlds where S exists, whatever is S is T. So we cannot have a world in which N is false. And so:

(VII) Necessarily N is true (i.e. necessarily everything that is S is T).

So we have the consequence that a certain law of nature is necessary. All that was required was that S is super-sensitive and N is a universal law asserting a property to hold of things that are S. And so we can assert the following principle:

(N1) Any universal law that asserts a property to hold of super-sensitive substances is necessary.

4 The down-and-up structure

The structure just examined is an instance of a more general structure that I have called the *down-and-up structure*. The down-and-up structure can be seen as a generalization of the forgoing in two respects.

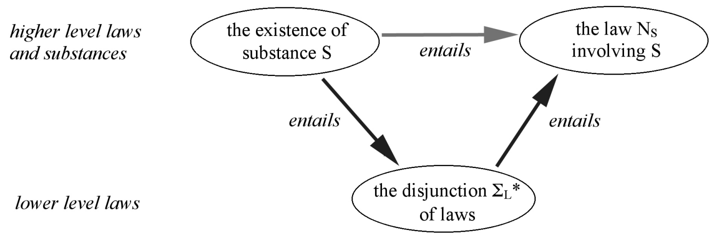

Figure 1: The down-and-up structure

First generalization. A substance can be super-sensitive to intermediate as well as to fundamental laws. Let S be super-sensitive to the law or conjunction of laws L, so that any adjustment to L would render S non-existent. In the above when considering F which is the conjunction of all fundamental laws, any non-fundamental law is a consequence of F, and *a fortiori* any law involving S, including N. But now we are considering an L that might be a single intermediate law or conjunction of just a few laws. In which case there is no longer a guarantee that any law involving S is a consequence of L. Nonetheless, in *some* cases of a substance S, intermediate level law L, and higher level law N_S that involves S, S could be super-sensitive to L and that among L's consequences is the law N_S. In such cases, there is no world in which S exists and there is a counterexample to N_S; and so N_S is necessary.

Second generalization. A lower level (but perhaps non-fundamental) law, L, may play a part in explaining why the substance S exists. S may not be super-sensitive to L. There may be variations on L that permit S to exist. Let the set of possible laws that are variations on L that allow S to exist be Σ_L. Let N_S be a law such as the N_S in the case considered in the previous paragraph, where N_S is a consequence of L and N_S involves S. Although N_S is a consequence of L it need not be a consequence of some $L_n \in \Sigma_L$. However, in particular cases N_S will be a consequence of each of the laws in Σ_L. In such cases, although variations on L will exist that permit S to exist, every one of these variations also entails N_S. So again, there will be no world in which S exists but in which there is a counterexample to N_S, and again N_S will be necessary. To formulate the point another way: let Σ_L* be the disjunction of all the members of Σ_L. The sensitivity of S whereby the existence of S requires the truth of one of the variations on L in Σ_L means that the existence of S entails Σ_L*. The fact that N_S is a consequence of every member of Σ_L means that Σ_L* entails N_S So the existence of S entails the truth of N_S the law that involves S.

With these generalizations in place we now have the 'down-and-up' structure, as shown in Fig.1. Let us call the set Σ_L above, *S's range of sensitivity with respect to L*. To be precise, a set Σ_L is S's range of sensitivity with respect to an actual law or conjunction of actual laws L iff Σ_L is the smallest set of laws (or conjunctions of laws) containing L that are possible alternatives to L such that without the truth of one of the members of Σ_L, S cannot exist. (If L is irrelevant to the existence of S, then Σ_L is empty.) S is super-sensitive to L if S's range of sensitivity to L is the singleton set of L.

Let us call a set N's *range of robustness*, when that set is a maximal set such that every one of its members is a law or conjunction (of laws) that entails N. The conclusion that the down-and-up structure yields a law that is necessary may be summarised in the following proposition:

> (N2) Let N_S be a law involving a substance S. N_S is necessary if there is some lower level law L such that S's range of sensitivity with respect to L is a non-empty subset of N_S's range of robustness.

5 Sensitivity I

It is dialectically useful to be able to show that the down-and-up structure does in fact exist in the actual world. I shall leave this until a later section. It is first important to argue that the particular phenomenon of sensitivity does in fact exist. There should be no doubt that the 'up' part of the down-and-up structure exists. This part just asserts that some higher level laws are consequences of lower-level laws. And that is just what is meant by calling those laws 'higher-level'. And there is no doubt that such higher-level laws do exist. It is less immediately clear that the existence of a substance can be sensitive to lower-level laws. So in this section I shall examine the 'down' part of the down-and-up structure.

I shall start with a picture of the relationship of the actual world and its laws to other possible worlds and their laws. We might think of the laws as forming a hierarchy, with fundamental laws at the bottom and non-fundamental laws above them. A non-fundamental law may is a consequence of perhaps other non-fundamental laws at lower levels. Ultimately all laws are consequences of the fundamental ones. As one might expect and as the evidence of the sciences suggests that while there are many laws at less fundamental 'levels', there are probably very few fundamental laws. There may even be just one basic law of which all the non-fundamental laws are consequences. Thus we can think of the laws as forming a big 'V' somewhat akin to the big 'V' of hierarchical set theory or Russell's typed hierarchy of classes (although strictly the analogy should be with the axioms of set theory and the theorems that are their consequences, not the sets themselves). Let us consider Russell's hierarchy. In this case we can take the 'V' and cut off its sharp point, removing all the classes below a certain type. The class-formation principles of the hierarchy would still leave the remainder of the 'V' intact.

It is tempting to think that we might do something similar with the 'V' of laws. Might there not be a world with many of the same, indeed all the same non-fundamental laws from a certain level up, but without the actual fundamental laws (and without the non-fundamental laws from the given level down)? The question is significant because it might seem to give grounds for thinking that there is no sensitivity. Let D be some non-fundamental law, concerning a substance S, in world *w* (which we may take to be the actual world). Imagine that there is a world *w** which is like *w* except that the laws below the level of L are removed—the 'V' is truncated. In *w* D is a non-fundamental law, but in *w** D is fundamental. In *w** S is fundamental substance. If what remains is genuinely the same as in *w* and if fundamental laws are contingent, then D is contingent in *w**. In which case there is another world *w*† in which L does not hold but S exists.

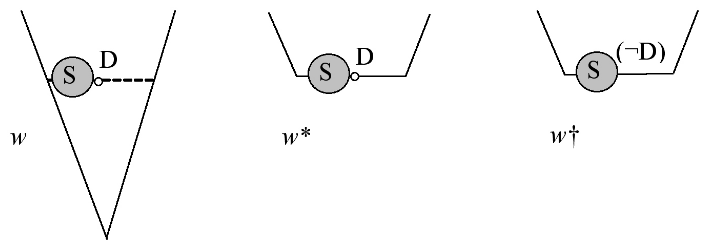

Figure 2:

For example, let S be water and D be the law that water dissolves salt. Then *w** is a world where 'water dissolves salt' is a fundamental law and water is a fundamental or basic substance. (It is possible that some pre-atomist chemists thought that they lived in such a world.) But if 'water dissolves salt' is fundamental, and we accept the contingency of fundamental laws, then in *w*†, the fundamental substance water exists but that law does not hold if it.

Before proceeding I should note that the picture is flawed in ways that will not concern me at length. First, the picture assumes that we can meaningfully talk of 'levels' of laws as if there is some division of laws into those at the same level of D and above and those below. We can do this for sets (their cardinality will serve to differentiate them), but not for laws. The legitimate and somewhat rough-and-ready idea that some laws are more fundamental than others does not imply that for any two laws there is a fact of the mater as to whether they are equally fundamental or one is more fundamental than the other. Secondly, the picture implies that as long as we have all the laws at the same level as D, we do not need the fundamental laws to generate the laws yet higher up—D and its counterparts will be sufficient. But that is not true. Suppose that H is a consequence of two laws, D and some law F more fundamental than D. H will be higher up than D. But it may not be possible to generate H only from laws at the same level as D. So *w** won't be just like *w* from D up—because it lacks F, it will lack H. While such objections are important in showing the flaw with the picture under consideration I'll put these objections on one side to concentrate on others of more immediate significance.

I shall accept without argument the Kripkean claim that the constitution of substances is essential. I aim to show that this claim can be extended to include the claim that the laws underling the existence of a substance are essential also. Or rather, what follows might be considered as spelling out an aspect of the Kripkean claim that was always there but not fully recognised. The argument is, in effect, an elaboration of the following idea. Just as XYZ is not water, despite sharing the properties of water from a certain level up, *w** is not identical to the 'upper part' of *w*, despite their having the same appearance (i.e. sharing an analogous metaphysical structure) from a certain level up. Just as what makes water water is a mater of its constitution (what it is made of and how its constituents are arranged), what make L the law that it is, is the fact that it is a consequence and manifestation of the fundamental laws of *w*.

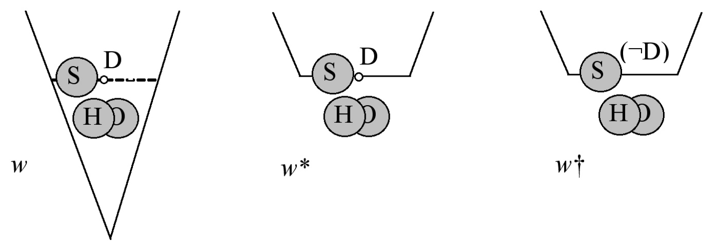

Figure 3:

Let us accept that water is necessarily H_2O. This already shows that the picture given in Fig.2 is badly mistaken, since that picture takes water to be fundamental substance in *w**. So the picture will have at least to be modified, as in Fig.3: *w** will have to include hydrogen and oxygen.

Particularly when rehearsing Putnam's arguments concerning reference, we are apt to concentrate on the fact that water must contain hydrogen and oxygen and not anything else, including the mysterious X, Y, and Z. But being constituted of hydrogen and oxygen alone is not sufficient to make something water, as hydrogen peroxide (H_2O_2) shows. But nor is the correct ratio of the constituents sufficient, since a homogeneous mixture of hydrogen and oxygen gases in a molar ratio of 2:1 is not water either. So it is essential to water that it is composed of molecules in which two atoms of hydrogen and one of oxygen are appropriately bonded. So at the very least any world in which water exists is a world in which there are laws that will cause oxygen atoms and hydrogen atoms to bond in molecules of H_2O.

From this we may draw the following three conclusions:

(i) the picture in Fig.3 is mistaken in assuming that there is a world such as *w** in which there are no laws more fundamental than D;

(ii) therefore the picture cannot be used to show that there is a world *w*† in which D is false (but S exists).

(iii) there exists some degree of sensitivity—the existence of water requires that there exist some kind of lower level laws governing the bonding of hydrogen and oxygen.

Let 'B' denote the laws of chemical bonding as they are in the actual world. (These can be considered as complete and detailed versions of the valency laws.) Without those laws or some other laws to replace them water would not exist. The argument so far yields the conclusion that the set Σ_B, water's range of sensitivity with respect to the bonding laws, is neither empty nor the universal set. The picture we now have is:

In Fig.4 *w* is the actual world, where B is a non-fundamental law supporting the existence of the substance S. The world *w** is a world where B is a fundamental law; from the level of B up things are as they are in the actual world, including the existence of S. The world w° is a world close to *w** where a variant on B, B°, also supports S. B° is in Σ_B. World *w*† is a world in which no variant on B exists that supports the existence of S. For the down-and-up structure to exist, every world w° must be one in which D holds.

The next question is: how large is Σ_B? Is the existence of water highly sensitive with respect to B (in which case Σ_B is small)? Or could water exist in a wide variety of worlds with very different laws doing the job of bonding in the place of B? If the latter, then the chances are greater that there will be a world in which some replacement for B permits the existence of S, but the law D fails to hold, i.e. the down-and-up structure does not exist. So what is important for what follows is to establish whether any radical alternative to B is consistent with the existence of water. Consider an extreme case. A world does not have B; in it hydrogen atoms and oxygen atoms do not bond of their own accord. But a powerful sorcerer desires that oxygen atoms and hydrogen atoms should associate in such a way that mirrors their association in the actual world. And so by some other force that exists only as a manifestation of the sorcerer's will, it 'looks' as if there are water molecules in this world. The groups of two hydrogen atoms and one oxygen atom held together by the will of the sorcerer are not water molecules. We have pseudo-water, something that has the superficial features of water (just as XYZ) does, but is not water nonetheless. XYZ is not water because it contains the wrong materials; pseudo-water is not water either, since although it contains the right materials they are not bound in the right way.

This pseudo-water is clearly not water since what holds it together is not even very natural. But it is not the unnaturalness of the bonding that prevents pseudo-water from being water. Rather it is the fact that such bonding is so unlike the bonding we actually have that it creates a different substance. And so now the question must focus on intermediate cases, where the atoms are bound together by laws and processes less outlandish than the one described but nonetheless radically different from the actual laws of bonding.

This is a question, I believe, that is beset by considerable vagueness; for a range of possible alternatives to B it isn't possible to say with any high degree of justified confidence that what they give rise to is or is not water. (Note that there is also vagueness when it comes to the material of constitution: is identity of chemical constitution required for sameness of substance when dealing with very large bio-molecules, such as proteins?) Even so, there are considerations that point in the direction of a smaller Σ_B. We do not have to go so far as the sorcerer to find non-chemical ways of combining atoms. Clathrates are structures of atoms and molecules whereby an atom or molecule of one substance is trapped within the interstices of the molecule or crystal of another

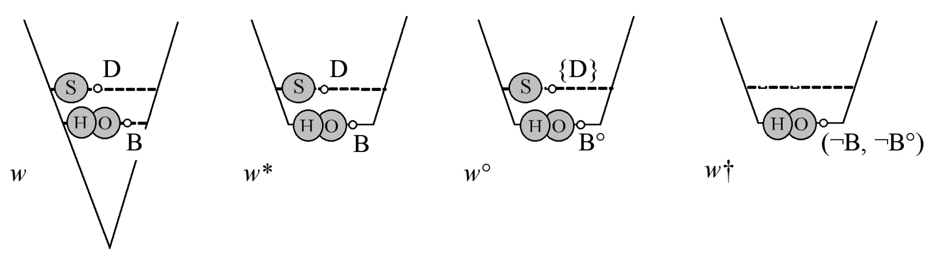

Figure 4:

substance. Clathrates are not regarded a compounds, but instead as mixtures, precisely because they are not bonded by chemical bonds, even though the forces that hold them together are perfectly natural. If the atoms of a clathrate were to bind together in exclusively chemical bonds, even in the same spatial arrangement, the result would be a different substance. By parity of reasoning, hydrogen and oxygen atoms hold together by anything other than a chemical bond would not yield a chemical compound, and *a fortiori* would not yield that chemical compound which is water.

At this point we may conclude that, on the basis of the model being employed, it may be difficult to assess the precise range of sensitivity of a substance. Nonetheless we know that there is a range of sensitivity that is circumscribed to some extent. That fact will lead to the down-and-up structure, and hence to the necessity of some law concerning that substance, if and only the range of robustness of some such law includes the substance's range of sensitivity. Whether that condition is met is an *a posteriori* matter. *A priori* investigation cannot tell us either the range of sensitivity of a substance with respect to a lower level law, nor can it tell us the range of robustness of some higher level law involving that substance. Nor can *a priori* investigation tell us that the former is never a subset of the latter. In which case *a priori* investigation cannot rule out the existence of the down-and-up structure.

The case for the existence of the down-and-up structure is strengthened by reflecting on *a priori* considerations that show that any substance is sensitive to the fundamental laws, and on *a posteriori* considerations concerning the possible nature of those laws. In the next section I will argue that all substances are indeed sensitive to the fundamental laws.

6 Sensitivity II and super-sensitivity

The discussion of sensitivity in the last section proceeded by allowing that we might treat a supporting law as fundamental. So we treated as a genuine possible world one in which both (a) the laws of bonding are slightly different; (b) possesses many of the same substance as the actual world (including the substance S under discussion). The conjunction of those changed laws of bonding will be in S's range of sensitivity. In this section I shall argue that this over-estimates the range of sensitivity (and so underestimates the likelihood of the down-and-up structure).

The picture we were working with in the preceding section was this. Let L be some actual law. Let L* the correlate of L in a world, *w**, in which the laws are truncated below the level of L. So L* is a fundamental law in *w** (even though L is not fundamental in *w*). Now consider *w*† in which the fundamental laws are similar but not identical to those in *w**. Now suppose that in *w* L is responsible for the existence of a substance S. In *w** there is corresponding substance S* supported by L*. In w°, L° is sufficiently similar (but not identical with L*), that L° can support the same substance S*. That is, S*'s range of sensitivity includes both L* and L°. The supposition that truncation leaves everything that remains intact (i.e. identical to its correlate in the untruncated world) allows us to say that L is identical to L* and that S is identical to S*. Since L° is in the range of sensitivity for S*, it is thus in the range of sensitivity for S. We may conclude then that Σ_L, may be fairly large.

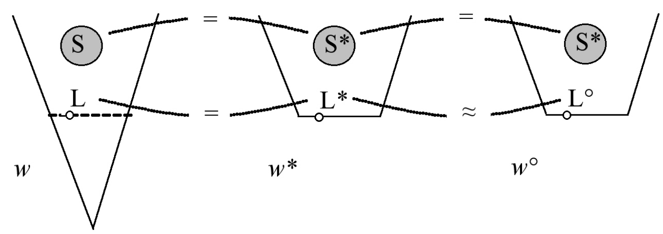

Figure 5:

In what follows I will argue that the picture just given is misleading and that *w* and *w** cannot be considered identical ‘from L up’, that L and L* are not identical and S and S* are not identical, and that L° is not part of Σ_L.

The constitution of S is essential. If S is water, then necessarily, if S exists at *w*, then so do hydrogen and oxygen. This consideration led us from the model depicted in Fig.2 to that in Figs 4 and 5. The same Kripkean considerations go for hydrogen and oxygen. These are constituted, necessarily, from electrons and protons and neutrons. So any world with water is a world with electrons, protons, and neutrons. The same in turn goes for theses entities and their constituent entities (quarks) and for those entities and so on downwards. If there is some fundamental kind of entity in the actual world that all matter is made of, then any world with water is a world with those fundamental entities. It will be recalled that at the outset of the preceding section these Kripkean considerations obliged a move from the model *w** (1) to model *w** (2), in Fig.6. The same considerations have moved us from there to *w** (3) and ultimately to *w** (4).

Now look at S and S* in Fig.5. The picture we are looking at says that S and S* are identical. Since any world with S (taking S to be water for the time being) is a world with electrons, with quarks, with strings, and with the fundamental entities, it follows that *w** must contain all these entities. Now presumably the fundamental entities in the actual world are governed by very deep level laws indeed (perhaps the fundamental laws themselves). But *w** is a world without the deepest level laws; it has only higher level laws. In consequence, *w** is a world with all our deeper level entities, including the fundamental ones, but without the laws that govern these entities. This is absurd enough, that there should be these entities that are nomically and hence causally

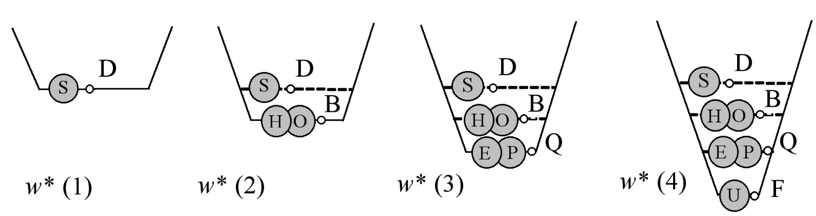

Figure 6:

inactive. But the problem is worse than that. These entities are supposed not only exist but also to constitute the entities and substances higher up. But, as I have urged above, 'to constitute' does not mean simply 'to be present in'. To be a micro-constituent of something else an entity must play a part in explaining the properties of the macro entity. But in the absence of laws governing the micro-entities they can explain nothing. In short, the argument is this: Kripkean essentiality of constitution requires both (i) that S's actual constituent entities (all the way down) exist in all worlds in which S exists and (ii) that these entities explain S's properties. (ii) requires that there are laws governing the entities, all the way down. Hence a world such as it is claimed *w** is, with S=S* but without the lower level laws, cannot exist. And so in so far as anything like *w** exists nothing in it is identical to S.

The important consequence of this is that a higher level substance such as water is sensitive not only the laws governing its immediate constituents (hydrogen and oxygen) but also to laws governing mirco-constituents all the way down to the fundamental constituents of matter. Now the laws governing the ultimate constituents of matter will be close or identical to the fundamental laws of nature. Such laws will also be laws that have as their consequences all the higher-level laws governing the behaviours of substances. Let us further suppose that these low level or fundamental laws have a form that allows for little or no variation that permits the higher level substances to exist. If they allows for no variation then the higher level substances will be super-sensitive and all the laws concerning these substances will be necessary. Even if some variation in the low level laws still permits the existence of the substances, it may be that the variation is so slight that all the variations will have laws concerning the substances as consequences. And so we will have the down-and-up structure nonetheless.

7 A functionalist objection

8 An example—the discontinuous emission spectrum of hydrogen

Earlier sections have shown that sensitivity and hence the 'down' part of the down-and-up structure do exist. Since the 'up' part is not in question, we have the ingredients in place for the whole structure. What is needed to make it occur is for some substance S, for some law N involving S, and for some lower level law L, that S's range of sensitivity with respect to L is a subset of N's range of robustness. It will be a helpful illustration to show that this structure does indeed occur in the actual world. As I will explain, in this example S will be hydrogen, N will be the law that hydrogen emits a discontinuous spectrum, while L will be Schrödinger's equation.

When samples of substances are heated to incandescence (typically as a gas at low pressure) their atoms emit light. It was discovered experimentally that the spectra emitted are not continuous but discrete. That is, the wavelengths of the light emitted by the atoms take only certainly values (not all the values on some portion of the total possible spectrum). In 1885 Johann Balmer identified a formula for some of the lines in the emission spectrum of hydrogen:

$$\frac{1}{\lambda} = R\left(\frac{1}{4} - \frac{1}{n^2}\right) \tag{1}$$

which states that for each natural number *n* there is a spectral line of light with wavelength λ (R is a constant, now called the Rydberg constant). This was a purely empirical discovery. A continuous spectrum would also have been consistent with what was then known, and indeed the existence of spectral lines was a surprise. Thereafter other line series were discovered (the Lyman, Paschen, and Brackett series). These and the Balmer series are special cases of the Rydberg equation:

$$\frac{1}{\lambda} = R\left(\frac{1}{n^2} - \frac{1}{n'^2}\right) \tag{2}$$

where n and n' are distinct natural numbers.

Epistemically the existence of the various Rydberg series was contingent. Physicists had no reason to expect the series and indeed their existence was surprising and inexplicable within classical physics. It was a triumph of the Bohr model of the atom that it was able to explain the discrete emission spectra in terms of the quantisation of the energy levels of electrons and indeed was able to retrodict exactly the Rydberg equation. In due course the relatively primitive, semi-classical quantization involved in Bohr's model gave way to a model of the hydrogen atom derived from the full Schrödinger equation. It is clear therefore, if modern physics is even only half-right, that the discrete spectra of the Lyman, Balmer, Paschen, and Brackett series are phenomena that are consequences of the quantum nature of the hydrogen atom.

The quantum nature of the hydrogen atom (and indeed of any other atom) is an essential property of that atom. It is difficult to know what a fully worked-out classical model of the atom would be like, for the Rutherford atom and its plum pudding predecessor did not receive quite the detailed treatment that the Bohr atom and its successors received. The Rutherford atom would allow for continuous spectra, since an atom held together by Coulomb forces, akin to the solar system held together by gravitational forces, would allow orbits of radii that vary over a continuum of values, just as the radii of planetary orbits can have values in a continuous range. Electric charges under acceleration (and so those in circular motion in particular) emit electromagnetic radiation. Hence the Rutherford atom can emit a continuous spectrum.

Of course, the immediate objection to the Rutherford atom is that the orbiting electrons will emit radiation at all times, not just when excited by being heated. Thus the orbiting electrons will lose energy and spiral into the nucleus. So the Rutherford atom is unstable and would have a very short life. I mention this in order to make it clear that it is far from clear that there could be a possible world with Rutherford atoms. It is not sufficient to say 'consider a world governed by classical physics (viz. classical electromagnetism and the Rutherford atom)', for there are no stable atoms in such a world. So if there is a world in which there are Rutherford atoms it will look quite unlike the actual world and will not be a world governed by classical physics. For there will have to be major deviations from classical physics in order for the Rutherford atom to be stable—energy will not be conserved or accelerating charges will not emit radiation, etc. So we cannot be sure that there really is a world where there are Rutherford atoms, and if there is, we cannot be entitled to think that it will be at all like the actual world.

More specifically and more importantly, to allow that some such model could be realised in some possible world and that it would yield a continuous rather than discrete emission spectrum is not to allow that such a world is a world with hydrogen atoms (albeit of a different sort). For a proton and an electron held together by a mechanism other than the quantum mechanical one is not a hydrogen atom. If Kripke and Putnam are right, then it is not just necessary that a hydrogen atom contains a proton and an electron, but also that these are combined in the appropriate way. While water is necessary hydrogen and oxygen, that is not all that is necessary, for a mixture of hydrogen and oxygen gases is not water, nor is a hydrogen peroxide. Similarly, an electron and a proton in proximity are not ipso facto a hydrogen atom, nor is an electron-proton pair held together by some other mechanism such as a very strong version of gravity. If one accepts these Kripkean intuitions, then one should also accept, I believe, that an 'atom' is not an atom of hydrogen unless it is held together by a mechanism sufficiently similar to the mechanism that holds together those samples of hydrogen that in fact fix the reference of 'hydrogen'.

This argument may be taken further. The standard model explains the existence of all known matter. For example it explains the existence of protons as two up quarks and a down quark held together by the exchange of gluons. The standard model is essentially quantum mechanical. So absent quantum mechanics and we absent the existence of protons and indeed of any other matter we are aware of. Hence a world with non-quantum mechanical 'atoms' is a world without, for example, hydrogen, for hydrogen is essentially that substance whose atoms have a single proton in their nucleus. Additionally the standard model legitimates the extension of the Kripkean intuition form the substance of constitution to the manner of constitution. An objector might agree that necessary a hydrogen atom is composed of a proton and an electron but be less convinced that it is necessary that the manner of composition necessarily be quantum mechanical rather than something-like-classical. However, if things are as the standard model says they are, then the manner of composition (viz. the internal, structural forces) is itself to be identified with the exchange of particles, such as the gluons in the case of the quarks in the proton. Thus the matter of constitution versus manner of constitution distinction looks to be blurred, rather as the mortar holding bricks together is part of both the manner *and* the matter of the constitution of the wall.

Thus we have the down-and-up structure. The existence of hydrogen entails the existence of protons and thereby of the standard quantum mechanical model of particle physics or something sufficiently similar. 'Sufficiently similar' here will include being quantum mechanical and being governed by Schrödinger's equation or some cousin thereof. Since it is Schrödinger's equation (or, more generally, the quantum mechanical nature of the atom) that is responsible for the Balmer and other spectral lines, any such hydrogen atom will necessarily show a discrete rather than continuous spectrum. Therefore, necessarily a hydrogen atom emits a discrete spectrum. Looked at conversely, we saw that a world where an 'atom' emits a continuous spectrum is one inn which that atom is not governed by Schrödinger's equation nor by anything like it. But such a world is a world without our particles and atoms, and so any 'atom' in this world will not be an atom of hydrogen. Hence there is no possibility of a world with hydrogen but which has a continuous spectrum.

9 Fundamental laws

As mentioned, knowing whether the down-and-up structure exists depends upon *a posteriori* considerations. Such considerations gave us good grounds to think that the down-and-up structure exists in the case of the law that salt dissolves in water. This required thinking about supporting laws no deeper than Coulomb's law of electrostatic attraction. Thus the discussion did not go beyond the degree of sensitivity discussed in §5. But in §6 we saw that there exists much more sensitivity in the world than that suggests. We saw that the existence of a substance is sensitive to laws all the way down to those governing the ultimate constituents of matter. If we knew what these laws are, we could assess the range of sensitivity of substances to these laws and we might thereby find that they are super-sensitive and thus that high level laws are all necessary.

We do not however have the relevant knowledge of those laws. And so we are not in a position to say that we know that substances are supersensitive or even sufficiently sensitive to lower level laws that the down-and-up structure is ubiquitous. Nonetheless, there is scientific evidence that gives us some understanding of what the fundamental laws will be like. And this evidence shows us that they are likely to have those features that makes for considerable sensitivity to them. I'll briefly discuss three sorts of area where scientific developments point in the direction of higher sensitivity.

<u>The number of fundamental laws.</u>

<u>Fundamental constants</u>

10 Epistemological considerations

A full demonstration that the law that salt dissolves in water instantiates the down-and-up structure would require more technical detail than would be ether possible or appropriate in this paper. That fact itself demonstrates something significant, that whether or not the down-and-up structure exists must be an *a posteriori* matter (so long as it is not *a priori* that the fundamental laws are necessary).

This means that when some law is discovered, say by an inductive inference from an observed pattern, we will not be in a position to say whether, in virtue of the down-and-up structure, it is necessary or contingent, until we know the details of the underlying mechanism for that law. Sometimes that knowledge will allow us to say that the down-and-up structure does exist, as I think it does for the law that salt dissolves in water. So sometimes we will be able to know that a law is necessary.

But knowing that a law is contingent will be much more difficult. Knowing that for a law N involving S that it does not instantiate any down-and-up structure will require an investigation of the relations of sensitivity and robustness of S and N as regards *all* laws more fundamental than N. Let us imagine that further scientific details show that that water's range of sensitivity to Coulomb's law is not after all a subset of the range of robustness of the law that salt dissolves in water. That will not be enough to allow us to conclude that the latter law is contingent. Coulomb's law is not a fundamental law of nature. So there will be some more fundamental law or conjunction of laws, K, underling that law. So even if the down-and-up structure does not hold with respect to Coulomb's law it might hold with respect to K.

As a consequence of this, in order to know that the down-and-up structure exists nowhere in the actual world requires (a) knowing the fundamental laws; and (b) knowing exactly how the non-fundamental laws and substances depend on the fundamental laws. That is a lot to know, perhaps too much to know. In any case it is clear that we don't have that knowledge now. Consequently we certainly do not know that all the laws of nature are contingent.

An interesting aspect of this discussion is that it does not merely recapitulate Kripke's point that some necessary truths are knowable only *a posteriori*. It goes further than that and says that it is *a posteriori* whether a certain truth is necessary or contingent. One we have taken on board Kripke's (*a priori*) arguments, we know for an identity statement or a statement describing the constitution of a substance, that the statements in question are, if true, necessarily true. But what the down-and-up structure shows is that for a law statement we may not know whether, if true, it is necessarily true. One can know a law statement to be true without knowing its modal status.

I do not wish to suggest that we should be startled by this conclusion. After all it is quite possible to construct cases of propositions we know to be true without being able to know their modal status. Let p be any true, contingent, proposition that is known *a posteriori*, and q be some proposition of advanced arithmetic, whose truth is not known (such as Goldbach's conjecture). Then $p \vee q$ is a proposition known *a posteriori* to be true, but whose modal status is unknown (if Goldbach's conjecture is true then $p \vee q$ is necessarily true, if the conjecture is false then $p \vee q$ is contingently true). And if Goldbach's conjecture or some other proposition in the place of q is an undecidable proposition of arithmetic, then it may be impossible to know the modal status of $p \vee q$.) Such cases notwithstanding, it is instructive to have a non-gerrymandered case 'found in nature', so to speak.

11 Conclusion