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### Necessary Laws and Chemical Kinds

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# NECESSARY LAWS AND CHEMICAL KINDS

Nora Berenstain

Contingentism, generally contrasted with law necessitarianism, is the view that the laws of nature are contingent. It is often coupled with the claim that their contingency is knowable *a priori*. This paper considers Bird's [2001, 2002, 2005, 2007] arguments for the thesis that, necessarily, salt dissolves in water; and it defends his view against Beebee's [2001] and Psillos's [2002] contingentist objections. A new contingentist objection is offered and several reasons for scepticism about its success are raised. It is concluded that certain higher-level laws describing the behaviours of molecular compounds may be necessary due to their dependence on underlying physical laws, and that the modal status of laws of nature cannot be determined *a priori*, as the structural features of the substances and properties they govern must first be investigated.

**Keywords:** laws of nature, modality, scientific essentialism, *a posteriori* necessity, conceivability, possibility

## 1. Introduction

Before the advent of semantic rigidity, the dominant view among philosophers was that all necessary truths are knowable *a priori*.<sup>1</sup> Kripke shifted the philosophical consensus to the view that some necessary truths are knowable only *a posteriori*. Though he introduced rigid designation as part of an attempt to formulate a semantic theory of proper names, he intended the notion to extend beyond proper names, to include the semantic behaviour of natural-kind terms. While he did not explicitly formulate an account of what it means for natural-kind terms to be rigid, he saw their rigidity as supporting the necessity of theoretical identifications, statements such as 'gold is an element' and 'water is H<sub>2</sub>O' that he took to be both empirically determined and necessary if true. While current consensus is that Kripke showed there to be necessary truths that are knowable only *a posteriori*, such truths are generally considered to be the exception rather than the rule, even when it comes to statements that involve natural-kind terms and that express laws of nature.

In the past decade or so, several philosophers have argued for views that identify the nature or essence of a natural-kind property with the behaviours, as described by the laws of nature, that instances of the kind generally exhibit. Notable among them are Shoemaker's causal theory of properties [1998], Hawthorne's causal structuralism [2001], and Bird's dispositional essentialism [2007]. These views share the consequence of making Kripkean statements of *a posteriori* necessity commonplace, as laws describing the

<sup>1</sup>If they are knowable at all. Some take Gödel's theorem to show that there are necessary truths that are not knowable.

behaviour and interaction of natural kinds will be both metaphysically necessary<sup>2</sup> and discoverable only empirically. However, one need not start by assuming such a view of properties in order to argue that there is more *a posteriori* necessity around than we usually think, and that it is frequently to be found in the laws of nature.

Bird argues [2001, 2002, 2005, 2007] for the view that some higher-level laws of nature may turn out to be necessary, given a certain ‘down-and-up structure’ of supervenience they have on lower-level laws.<sup>3</sup> Suppose there is a higher-level law that describes the behaviour of some substance and that that substance can exist only given a certain underlying law.<sup>4</sup> So as not to beg the question, we may assume that the underlying law is contingent. If the underlying law entails the truth of the higher-level law, then even if the underlying law is contingent, the higher-level law turns out to be necessary. We can see this if we realize that, in order for a world to provide a counterexample to the higher-level law, the world must be one in which the substance exists but the law fails to hold. Worlds in which the substance does not exist are worlds at which the law is vacuously true. In order for a universal claim of the sort ‘For all  $x$ ,  $x$  is  $F$ ’ to be false at a world, the world must contain at least one  $x$  that is not  $F$ . So the world must contain at least one  $x$ . Thus, if the underlying law entails the truth of the higher-level law, the higher-level law turns out to be metaphysically necessary even if some possible worlds do not contain the substance whose behaviour is governed by the higher-level law. This runs counter to *contingentism*, the view that all laws of nature are contingent. Further, since the structure of these higher-level laws can only be discovered empirically, their necessity is an *a posteriori* matter. This runs counter to another view, frequently coupled with contingentism, that the contingency of laws of nature is knowable *a priori*.

The argument given above has wide-ranging consequences for the way we think about metaphysical modality and modal epistemology. Widespread *a posteriori* necessary laws of nature would pose a substantial challenge to the reliability of conceivability as a guide to possibility. The more frequently that instances of *a posteriori* necessity appear, the more serious the failure of conceivability is. The arguments in this paper suggest that instances of *a posteriori* necessity are likely to appear whenever scientific investigation and theorizing are involved, and are thus far more common than we usually think they are.

Further, the existence of a necessary law of nature shows that metaphysical necessity is more restricted than mere logical necessity. Thus, neither a Lewisian principle of recombination<sup>5</sup> nor our unrefined pre-scientific modal intuitions can offer reliable assessments of what is metaphysically possible.<sup>6</sup> Such purely *a priori* heuristics are blind to many of the structural features of

<sup>2</sup>This is because the nature of property is identified with its causal profile or dispositions, as described by the laws of nature.

<sup>3</sup>Here, a ‘higher-level’ law is any law that is not part of fundamental physics. Some higher-level laws will be lower-level laws *with respect to* other higher-level laws (e.g. laws governing cell division will be lower-level with respect to laws governing multicellular organisms).

<sup>4</sup>Use of the term ‘substance’ is not meant to assume any specific metaphysical picture.

<sup>5</sup>The principle of recombination attributes metaphysical possibility to all combinations of objects and properties that are not logically inconsistent.

<sup>6</sup>Bealer expresses a view of the latter sort in [2004].

the world uncovered by scientific investigation. The inter-structural relations that hold among higher- and lower-level laws, and between laws and substances, are features of the world that are discovered empirically and are key to our understanding of the metaphysics of laws.

Particularly when it comes to the special sciences, it is imperative that we know how these higher-level laws relate to underlying laws of physics, if we are to determine the metaphysical status of the former. Some philosophers assume that if a law is *ceteris paribus*, as laws of the special sciences are often taken to be, then the law must also be contingent. But a law's being contingent upon certain conditions is not the same as the law's being *metaphysically* contingent. For if the law holds in every world in which the conditions obtain, then the law, though *ceteris paribus*, is metaphysically necessary. If we take some generalization to be a law in the actual world, despite its *ceteris paribus* nature, then we should take it to be necessary if it holds, *ceteris paribus*, in all possible worlds. But we cannot know without empirical investigation whether or not it does so. As Bird [2002: 258] puts it, 'If we discover some higher-level law experimentally but do not know what makes it hold, we will not be in a position to know whether it is necessary or not.' Thus we cannot determine *a priori* whether *ceteris paribus* laws, the higher-level laws of the special sciences, are necessary or contingent.

Responses to Bird have focused primarily on attacking the example he uses to illustrate down-and-up supervenience, but they have tended to miss the point of Bird's original argument. The attacks presuppose *a priori* that certain scenarios are straightforwardly metaphysically possible, which is just the methodology against which Bird's argument warns. In what follows, I defend his thesis, that the *ceteris paribus* law that salt dissolves in water is necessary, from several such misguided objections. Beebee's [2002] objection proposes a scenario in which a disjunctive form of Coulomb's law would allow for the failure of salt to dissolve in water, and Psillos [2002] aims to provide a counter-example by imagining a world in which the structure of the water molecule and thus its polarity differs from its structure in the actual world. I dismantle Beebee's objection by showing (i) that the suggested scenario cannot act as a counter-example to the law, and (ii) that there is likely no change to Coulomb's law that could allow for the scenario in the purported counter-example to occur. I respond to Psillos's objection by attacking its problematic assumption that a molecule of H<sub>2</sub>O could form a different structure than the one it forms in the actual world. Finally, I outline the most promising objection that the contingentist could offer, and I give some reasons for thinking that even this stronger objection may not succeed. I conclude that the modal status of the law that salt dissolves in water is an empirical matter, and I suggest that instances of *a posteriori* necessity may be more widespread than we imagine.

## 2. Salt, Water, and Dissolution

Bird's argument applies primarily to those laws of nature that describe the interaction of two substances, where the interaction of the substances is

explained by some further underlying law. As an example, he uses the law that salt dissolves in water (I'll call this higher-level law L)<sup>7</sup>. The argument runs as follows:

- (1) Necessarily, the existence of substance *s* requires the truth of underlying law C.
- (2) C entails L.
- (3) For L to be contingent, there must be a world *w* at which *s* exists and L is false.
- (4) Hence, L is necessarily true.

In the case of salt and water, we understand the underlying law C to be Coulomb's law, which governs electrostatic attraction.<sup>8</sup> For it to be contingent that L, there must be a world in which salt and water exist but C fails to hold, as L will be vacuously true in worlds where salt or water fail to exist. As it turns out, the existence of salt and water requires, necessarily, the truth of C. So there is no world in which salt and water exist but C fails to hold, and law L turns out to be necessary.

To support premise 1, Bird takes for granted that Kripke- and Putnam-style arguments about the essentiality of certain natural-kind properties can be extended to show that the structural properties of the water molecule and salt crystal are also essential.

Kripke takes it to be a necessary fact that water is composed of hydrogen and oxygen and that salt is composed of sodium and chlorine. Bird thinks it follows that it is a necessary fact that water molecules are held together by covalent bonds and that salt lattices are held together by ionic bonds.<sup>9</sup> It is not the case that just any *mixture* of hydrogen and oxygen atoms is water; the atoms have to be held together in a certain way. They have to compose a *compound*. Similarly, it is necessary that any instance of a salt crystal is an instance of an ionically bonded sodium-chloride lattice. Bird takes the notions of *compound*, *molecule*, and *ionic bond* to be structural notions. It is important to note here that since ionic bonding is electrostatic in character, it is governed by Coulomb's law. Therefore, if ionic bonding must exist in order for salt to exist, and ionic bonding just is the type of bonding that exists by virtue of Coulomb's law, then Coulomb's law must obtain in any world in which salt exists.

<sup>7</sup>The argument-structure below is intended to provide a template for other instances of higher-level laws that govern substances that depend on lower-level laws. I'll focus specifically on the example Bird uses, in which *s* and *w* correspond to the substances salt and water, respectively.

<sup>8</sup>Bird does acknowledge that Coulomb's law *alone* is not enough to determine the solubility of salt in water, but he suggests that we can take C to be the conjunction of whatever other laws are required for salt to exist—e.g. Newton's second law, laws of quantum mechanics such as the spin-statistics theorem, the Pauli Exclusion Principle, etc.—all of which, Bird argues, will determine that salt dissolves in water.

<sup>9</sup>While it is worth noting that all ionic bonds have some covalent character, nothing much turns on this point.

In order for Bird's argument to be successful, it must be the case that it is essential to salt that its constituent atoms are ionically bonded, and it is essential to ionic bonding that it is electrostatic in character. Bird's support for these assumptions relies on the claim that Kripke-Putnam arguments for scientific essentialism can be extended to structural properties; and this claim warrants further explanation.<sup>10</sup> I mentioned earlier that one need not assume Bird's dispositional essentialism in order to come to his conclusion that salt necessarily dissolves in water, and this claim also deserves greater attention.

Most are familiar with Kripke's and Putnam's arguments for the necessity of such claims as 'water is H<sub>2</sub>O' and 'gold is the element with atomic number 79.' Let us define scientific essentialism as the view that some natural kinds have essential properties that can be discovered only through empirical investigation. These are expressed in statements of theoretical identification. Often, the essential properties expressed in these statements have to do with the underlying makeup of the substance or kind in question.

Scientific essentialism, which in this weak form is a widely accepted thesis, is to be contrasted with dispositional essentialism. Dispositional essentialism is the view that, fundamentally, all physical properties are essentially dispositional. Their essences are completely characterized by their dispositions to behave in certain ways when they are instantiated. On this view, the property of being gold just is the disposition to be dense, soft, shiny, more malleable and ductile than any other metal, and to have atomic number 79. Trivially, laws of nature come out as necessary on the dispositional essentialist view, as the fact that a property is essentially a collection of dispositions entails that, necessarily, a property's instantiations will behave in accordance with the dispositions it displays at the actual world. Note that dispositional essentialism is a much stronger view than scientific essentialism. While dispositional essentialism entails scientific essentialism, the latter does not entail the former. Scientific essentialism says that some properties have some of their features essentially. Dispositional essentialism says that all properties are essentially dispositions.

Now suppose we introduce a new category of essentialism: structural essentialism. Structural essentialism says that some properties have some of their structural features essentially. For instance, we might take the statement 'Gravity is an attractive force between bodies whose magnitude is determined in part by the masses of the interacting bodies' to be a theoretical identification, and thus necessary if true. Indeed, structural essentialism is not a new category at all but is already subsumed by the first weaker kind of essentialism, scientific essentialism. Initially, scientific essentialism seems to be about intrinsic features of kinds while structural essentialism seems to be about extrinsic features. But there are some kinds, namely forces, whose natures are characterized not by any arrangements of little bits of stuff that compose them, but by their interactions, which are inherently extrinsic. So it

<sup>10</sup>It is worth noting that not everyone who accepts scientific essentialism does so for reasons based on the semantic rigidity of scientific terms.

should be no surprise that Kripke-Putnam arguments in these cases lead to certain structural features being essential.<sup>11</sup>

In the traditional scientific essentialism case, we consider whether that very water molecule could have been made of gold atoms. The answer seems to be ‘no.’ In the structural case, we consider whether or not gravity—*that very force*—could have been an attractive force that depended on the spin of particles, for instance. Again, the answer seems to be ‘no.’ Exactly the same intuitions are at play in both cases.<sup>12</sup> In the gravity case, the relevant essential feature is that gravitational force depends on the masses of bodies (rather than, say, on the spin of particles). As the essential property here is relational, this is an example of what I have been calling structural essentialism.<sup>13</sup> But there is no important difference in kind between the structural case and the sort of case that illustrates traditional scientific essentialism, such as the one noted above. These considerations show that we should take structural essentialism to be a part of the scientific essentialism to which the Kripke-Putnam arguments already commit us.

Is there any reason to think that the Kripke-Putnam arguments rely crucially on the essential features of a kind being about its constituent little pieces? There doesn’t seem to be anything in the structure of the arguments that relies on that. Indeed, Kripke’s own examples indicate that he already envisioned these arguments applying to relational properties as well as to constituent parts. In his discussion of the essentiality of origin, Kripke argues that a person could not have come from different biological parents. This claim suggests an endorsement of the essentiality of the constituent DNA from which a person comes, as well as the essentiality of the relation of being descended from one’s actual parents.

In the case of ionic bonding, its essential feature in the scientific-essentialist sense is the structure bestowed on it by Coulomb’s law, which governs electrostatic attraction between bodies. The mathematical formulation of Coulomb’s law is as follows:

$$F = k_e(pq/r^2)$$

This says that the magnitude of electrostatic force between two charged objects ( $F$ ) is directly proportional to the product of the two magnitudes of each charge ( $p$ ,  $q$ ) and inversely proportional to the square of the distance ( $r$ ) between the charges.

Just as we would take it to be necessary that gravity is essentially an attractive force whose strength between physical bodies increases in proportion to their mass, we would similarly take it to be the case that the essential

<sup>11</sup>Bird does not offer an analysis of what he takes structural properties to be, and I do not take him to be committed to any specific view of the matter. Let us assume a broad understanding of structural properties as those that primarily involve relations among some relevant entities. This broad notion of structure can thus encompass spatial and geometric relations, but need not be limited to them. We can also restrict the class of structural properties to include only those that feature in at least one law of nature, as we are concerned here with natural properties rather than with strange gerrymandered or Cambridge properties.

<sup>12</sup>If someone wants to block the extension of the Kripke-Putnam arguments to structural features of certain natural kinds, she has two options. Either she can give up the original Kripke-Putnam arguments altogether, or she can explain what the difference is between the intuitions that support the two cases.

<sup>13</sup>In the case of the salt crystal, the essential relational property is that its constituent sodium and chlorine atoms are bonded in a certain way, namely ionically (rather than, say magnetically).



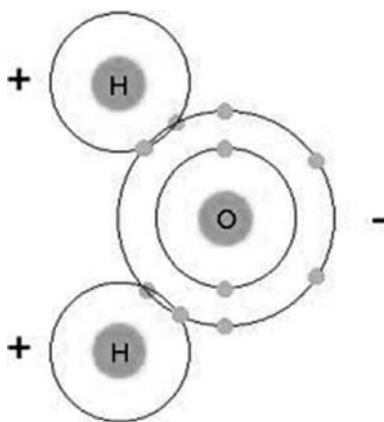


Figure 1: H<sub>2</sub>O molecule.

character of ionic bonding is determined by the law on which its existence depends, namely Coulomb's law. While it may follow that, necessarily, salt crystals and water molecules behave in the ways they do, we need not build the disposition to produce those behaviours into the scientific essence of ionic bonding. This way, there can be no concern that we are short-circuiting the relevant argument and begging the question by assuming dispositional essentialism.

Dissolution is the last empirical phenomenon we need to consider for our argument. The process of dissolution is partly electrostatic in character.<sup>14</sup> Recall the structure of the water molecule, shown in Figure 1. The hydrogen atoms are positively charged and the oxygen atom is negatively charged, making the molecule a dipole. The oxygen end of the molecule has a high polarity, which allows the molecule to pull sodium ions away from the surface of the salt crystal into the surrounding liquid, causing the crystal to dissolve. The salt crystal, shown in Figure 2, is a cubic lattice with alternating sodium and chloride ions. The bars between the ions represent the ionic bonds holding them together.

Since dissolution is an electrostatic process, the force that the water dipole exerts on a sodium ion on the salt crystal's surface is governed by Coulomb's law. Since that force is greater than the force exerted on the sodium ion by the surrounding chloride ions, the sodium ion is pulled away from the crystal's surface and into the liquid.

### 3. Beebee's Reply: Tweak Coulomb's Law

I'll now respond to an objection that I think misses the point of Bird's argument and that has not yet received an appropriate response in the

<sup>14</sup>Various kinetic properties determine the surface attraction between a mineral surface and an ion or molecule, as well as the rate at which the solute diffuses into the solution. Dissolution is not affected merely by electrostatic interaction; hydrophobic or hydrophilic interactions can play a role in dissolution, and solvation is often described in terms of thermodynamic properties of a solution, such as its heat or entropy.

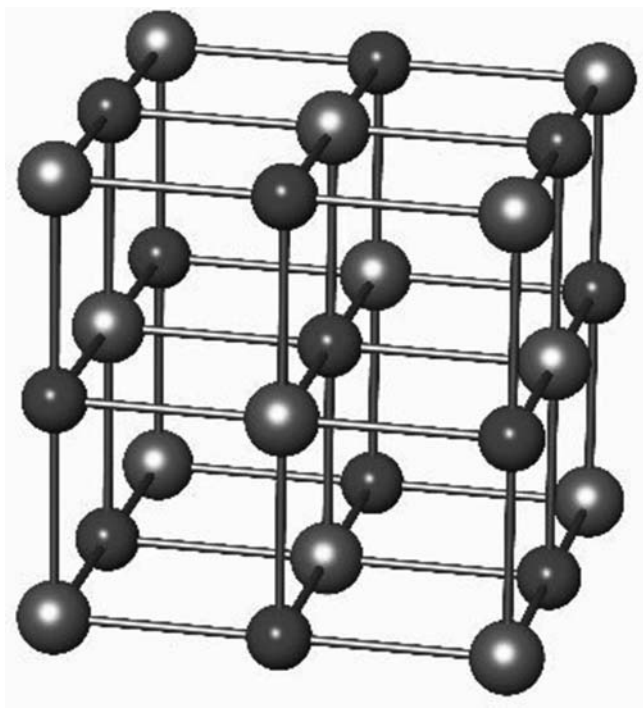


Figure 2: NaCl lattice.

literature.<sup>15</sup> Beebee's [2002] objection focuses on Bird's claim that the existence of salt requires or presupposes Coulomb's law (or something very much like it). Beebee first imagines a misguided objection to Bird. The imagined objection is this: Perhaps there is a world in which Coulomb's law is false but a law very like it is true, allowing for the existence of salt and water. She offers a response to this herself: A law that is similar enough to Coulomb's law to allow for salt and water to exist will also determine (something very like) the dissolution of salt in water.

Rather than positing a world in which something very like Coulomb's law is true, Beebee considers a world  $w_1$  in which Coulomb's law is replaced by a disjunctive law, so that the value of  $F$  generally equals  $k_e (pq/r^2)$ <sup>16</sup> but occasionally—and inexplicably—equals  $k_e (pq/r^4)$ .<sup>17,18</sup> Beebee acknowledges that, were  $F$  to always have this value at  $w_1$ , the world would be too different

<sup>15</sup>Bird [2002] addresses Beebee's objection, but his response focuses on the epistemic possibility that the down-and-up structure between higher- and lower-level laws holds in other cases besides this one; if it holds in even one other case, his original argument would still stand. I take the more direct approach of showing why Beebee's scenario cannot produce a counter-example to Bird.

<sup>16</sup>Its actual value.

<sup>17</sup>She supposes that setting the value of  $F$  to  $k_e (pq/r^4)$  will be a drastic enough departure from the actual world that the charge exerted by water molecules on sodium atoms will not be enough to pull the atoms away from the salt crystal of which they are part.

<sup>18</sup>It is worth noting that, in this world,  $F$  can no longer be considered a dimensionless constant of nature as it is in the actual world, making Beebee's envisioned world indeed quite different from our own. It is primarily this point on which Bird focuses in his [2002] response to Beebee and Psillos.

from ours for salt to form at all—but she stresses that, even though Coulomb’s law is false at  $w_1$ , there is still enough ‘relevant regularity’ in  $w_1$  for concepts such as *electrostatic attraction* and *ionic bonding* to be well-defined. While I do not dispute this claim here, I do not think it is unproblematic. What I wish to challenge is Beebee’s characterization of the interaction between salt and water molecules at  $w_1$ :

Suppose that, in fact, the ionic character of all lumps of salt at  $w_1$  is exactly the same as that of actual lumps of salt. So salt at  $w_1$  really does deserve to count as salt. But it just so happens that sometimes (or perhaps almost always), when one puts such a lump of salt into water, the electrostatic attraction exerted by the water dipoles on the sodium atoms is *not* such as to pull those atoms away from the sodium crystal and into the water. (I have no idea whether  $F = k_e (pq/r^4)$  will turn the trick, but something will.) So sometimes—almost always, if you like—salt fails to dissolve in water. So at  $w_1$ , it is not true that salt dissolves in water. Hence, it is not metaphysically necessary that salt dissolves in water.

This scenario, however, fails to constitute a counter-example to L, as  $w_1$  cannot simultaneously accommodate the existence of salt alongside the conditions required to prevent its dissolution in water. If the value of  $F$  at  $w_1$  differs for different regions of space-time, then the regions in which  $F$  does not equal  $k_e (pq/r^2)$  (the value it has at the actual world) are areas where salt will not form or exist. If  $F = k_e (pq/r^4)$  does ‘turn the trick’ to make the water dipoles fail to pull the sodium atoms away from the crystal and into the water, then it will *also* preclude the formation of stable water molecules and sodium crystals in the areas of  $w_1$  in which it obtains. It will thus still be the case in  $w_1$  that, wherever salt and water exist, salt dissolves in water.

What seems to be required for  $w_1$  to constitute a counter-example to L is for there to be a region of space-time in which  $F$  has the Coulomb value and in which salt is located, and for the area to border one in which  $F$  has the non-Coulomb value and in which there is water. But this is not yet sufficient.<sup>19</sup> In order for a molecule of salt to dissolve in water, it must be surrounded by water molecules. Let us suppose then that the area of space-time where the salt is located is exactly the area of  $w_1$  in which  $F$  has the Coulomb value. The surrounding area of  $w_1$  is one in which  $F$  has the non-Coulomb value, and it is occupied by water molecules. Thus, we may accurately say that the salt is in the water, but that the water fails to dissolve the salt. We shall assume that, if this case were possible, it would constitute a counter-example to Bird. But let us consider what else is required for this case to be possible.

If it is the case that the liquidity of water depends on Coulomb’s law holding, then it will not be possible for water molecules to join together into a liquid body in an area in which  $F = k_e (pq/r^4)$ . In liquid water, molecules of  $H_2O$  are bonded together through hydrogen bonding, an instance of dipole-dipole attraction, as shown below.

<sup>19</sup>For, a salt crystal spatially located next to a water molecule is not a case to which we may apply to the concept *dissolves*. It is no equivocation to say that, for salt to fail to dissolve in water, salt must be *in* water.

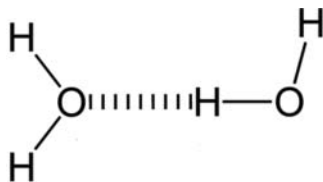


Figure 3: Two  $\text{H}_2\text{O}$  molecules are bonded together through hydrogen bonding.

Most other small compounds such as carbon dioxide, hydrogen chloride, and hydrogen fluoride are gaseous at room temperature. It is an anomaly that water is liquid at room temperature, and hydrogen bonding is responsible for this remarkable fact. Just as Bird showed that it is necessary that every salt lattice is held together by ionic bonds, we can see that it is necessary that every instance of liquid water is one in which  $\text{H}_2\text{O}$  molecules attach to one another through hydrogen bonding. Hydrogen bonding, being an instance of dipole-dipole attraction, is electrostatic in character. As such, it is governed by Coulomb's law [IUPAC 1997]. So it is not the case that there is a possible world in which liquid water can form in a region of space where  $F$  has a non-Coulomb value. Since both salt and liquid water must be present in a world in order for it to constitute a counter-example to L, and since the existence of both salt and liquid water require Coulomb's law to have the value that it does in the actual world (or something very much like it), we are again left without a counter-example to L.

Beebee's misstep is that she presupposes in the setup of her counter-example the very independence of laws that her opponent cautions against presupposing. In order for Beebee's scenario to provide a counter-example, it must be the case that water molecules in  $w_1$  can form a liquid despite the fact that the force allowing them to do so is far different from what it is in the actual world—different enough to prevent the stable formation of salt crystals. But since the existence of liquid water requires hydrogen bonding as much as the existence of salt requires ionic bonding, and both are governed by Coulomb's law, Bird's opponent cannot assume that the existence of liquid water at  $w_1$  can be stipulated independently of the value of  $F$  at  $w_1$ . In Beebee's attempt to construct a counter-example to Bird, her failure to consider liquid water's underlying structure serves as a perfect illustration of the fact that Bird's down-and-up structure is more ubiquitous than philosophers tend to assume.

Clearly, it is not the case that a disjunctive form of Coulomb's law can offer a counter-example to L. But there is another, more deeply rooted, problem with Beebee's scenario that has so far gone unmentioned. Her conviction that, in some possible world, the value of Coulomb's law will be both sufficiently similar to its actual value to allow salt to exist and sufficiently different from its actual value to prevent salt from dissolving in water demonstrates a misunderstanding of the nature of Coulomb's law. Coulomb's law is a relational value—a ratio of the product of the magnitudes of two charges to the square of the distance between them. Consider

again the English interpretation of  $F = k_e (pq/r^2)$ : ‘The magnitude of the electrostatic force between two point-like charged objects is directly proportional to the product of the magnitudes of each charge and inversely proportional to the square of the distances between the charges.’ We can see that  $p$  and  $q$  represent the magnitude of each charge and  $r$  the distance between the two charged objects. In order for salt not to dissolve in water, it would have to be the case that the value of  $F_1$ , where  $p$  and  $q$  are the charges of the sodium ions and the chloride ions in the salt crystal and  $r$  is the distance between them, is greater than the value of  $F_2$ , where  $p$  and  $q$  are the charges of the sodium ions and the water dipoles and  $r$  is the distance between them. While changing the Coulomb equation will change the numerical values of  $F_1$  and  $F_2$ , it will not change the relation of  $F_1$  to  $F_2$  from *less-than* to *greater-than*. And it is exactly this change of relation that is required for salt’s failure to dissolve in water. Not only will  $F = k_e (pq/r^4)$  not ‘turn the trick’—nothing will.<sup>20</sup>

Beebe assumes that there could be a value of Coulomb’s law that would leave untouched the strength of the ionic bonds holding the salt crystal together while weakening the electrostatic attraction exerted by the water dipoles on the sodium ions. She mistakenly conceives of the electrostatic attraction of the salt crystal’s ionic bonds as a separate phenomenon from the electrostatic attraction between the water dipoles and the sodium ions. They are not, however, different in kind, such that the strength of one can be manipulated independently of that of the other. They are both instances of electrostatic attraction (indeed, both of electrostatic attraction involving sodium ions), and as such they will rise and fall together with any change to Coulomb’s law.

#### 4. Psillos’s Reply: Change the Structure of the Water Molecule

Psillos’s [2002] objection attempts to put pressure on Bird’s claim that any world in which salt fails to dissolve in water is a world in which Coulomb’s law is false. Psillos imagines a world  $w_2$  in which Coulomb’s law holds but  $H_2O$ , having a linear rather than a bent structure, fails to dissolve salt. Psillos asserts that instances of  $H_2O$  in  $w_2$  would still be instances of water, and Bird [2002: 264] later agrees. Let us concede, for the sake of argument, that if such a world were possible, it would constitute a counter-example to Bird. It is far from clear, however, that there could be a molecule of  $H_2O$  with a linear structure. Thus, we should be reluctant to conclude that Psillos’s imagined world is a possible world.

Consider the following fact of chemistry: Every chemical compound has two formulae that must be expressed in order to identify it (and to individuate it from others). These formulae are (i) the *chemical/molecular formula*, which identifies each constituent element of the compound by its chemical symbol and indicates the number of atoms of each element found in a

<sup>20</sup>Of course, taking the reciprocal of  $(pq/r^4)$  would change the relation of  $F_1$  to  $F_2$  from *less-than* to *greater-than*. But this would seem to be just the sort of change to Coulomb’s Law that Beebe would take to be too drastic to allow salt or water to exist.

discrete molecule of that compound (e.g., water's chemical formula is  $\text{H}_2\text{O}$ ), and (ii) the *structural formula*, a geometric graphical representation of the molecular structure of a compound, which shows how the molecule's atoms are arranged and how its elements are chemically bonded to one another. There are six basic types of molecule structures, out of which all others are built: linear, trigonal planar, tetrahedral, octahedral, pyramidal, and bent. As I mentioned earlier the  $\text{H}_2\text{O}$ -molecule has a bent structure, and is always bent at an angle of 104.5-degrees.<sup>21</sup> If it were the case that a given molecule's structure were some primitive brute property, not determined by or derivable from the underlying features of the molecule's components, then Psillos's scenario might not be so problematic. But, perhaps unsurprisingly, this is not the case.

Certain facts about charge, repulsion, and equilibrium cement the inevitability of the  $\text{H}_2\text{O}$ -molecule's 104.5-degree angle.<sup>22</sup> The above mention of a molecule's structural formula touches solely upon the notion of molecular geometry, but each molecule also has a coordination geometry. While molecular geometry describes only the angles that form between the molecule's atoms, coordination geometry also includes the angles that form among the molecule's electron pairs. Consider the figures below, which show both the coordination and molecular geometry of the water molecule.

A molecule's molecular geometry is derivative upon its coordination geometry. Coordination geometry refers to the shape made by a molecule's distribution of electron pairs around its central atom. The  $\text{H}_2\text{O}$  molecule has two bonded electron pairs (each located at one of the molecule's two hydrogen atoms) and two lone (unbonded) pairs<sup>23</sup> [McQuarrie and Simon 1997: 379]. The lone pairs have a negative polar character and are located closer to the central atomic nucleus (the oxygen nucleus). Because of the repulsive force of the lone pairs, the hydrogen atoms are pushed further away from the central nucleus, to the point where the forces of the electrons on the hydrogen atoms are in equilibrium. At the point of equilibrium, the molecule has tetrahedral coordination geometry, as shown in Figure 4. In every case, the angles composed by the coordinates [H, H, lone-pair] are 109.5 degrees, and the inner angle [H, O, H] is 104.5 degrees. Thus, whether the geometry of a molecule is linear or bent (at a particular angle) depends on which structure is lowest in energy [1997: 384].

The important point is that the  $\text{H}_2\text{O}$  molecule has tetrahedral coordination geometry because that is the structure in which all of its forces are in equilibrium. If one were to attempt to change the structure of the  $\text{H}_2\text{O}$  molecule across possible worlds, one would first have to change the underlying

<sup>21</sup>The  $\text{H}_2\text{O}$  molecule is always bent at the 104.5-degree angle. When I mean by this is that the *equilibrium* angle of the  $\text{H}_2\text{O}$  molecule is always 104.5 degrees. I don't mean to suggest that it is never the case that an actual  $\text{H}_2\text{O}$  molecule is found bent at a slightly different angle. Rather, it is never the case that  $\text{H}_2\text{O}$  has some other equilibrium angle. This is, of course, meant to be compatible with facts about molecular vibration (i.e. the internal movement of atoms in a molecule).

<sup>22</sup>This is an idealized quantum-mechanical explanation of molecular geometry, and so certain subtleties are unavoidably washed out. However, in this case the idealized nature of the explanation does not affect its philosophical import.

<sup>23</sup>Of course, it is worth acknowledging that the quantum-mechanical nature of electrons means that the electrons are not 'located' in the classical sense. Rather, than having a determinate value, electrons' locations are represented by electron orbitals, which are probability clouds of their possible locations. But, for our purposes, the classical metaphor of location will be sufficient.

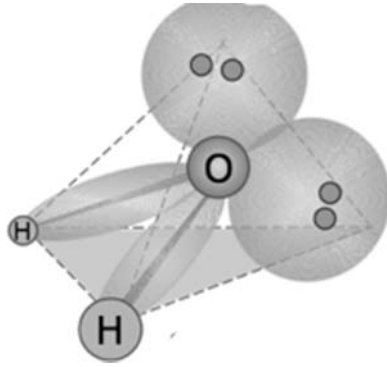


Figure 4: Tetrahedral coordination geometry of the  $\text{H}_2\text{O}$  molecule.

laws regarding charge, repulsion, and equilibrium. Changes of the sort required would be so drastic that it is not at all clear that the resulting worlds would be ones in which our scientific concepts *element* and *molecule* would have extensions. It is doubtful even that such changes would be possible. Recall the role that electron repulsion plays in creating a stable molecular structure. The fact that electrons repel one another results from their having the same charge. It is uncontroversial that fundamental particles of the same kind cannot differ from one another in their intrinsic properties, such as charge. Thus, it does not look like we can construct a possible world in which  $\text{H}_2\text{O}$  has a different structure, without radically altering essential properties of fundamental particles. Once we know that molecular structure is determined in part by an essential property of electrons, it is substantially more difficult to imagine a possible world in which only the structural properties of the  $\text{H}_2\text{O}$  molecule differ from the actual world while the underlying laws are left untouched.

### 5. Best Contingentist Reply: Posit an External Force

The clearest response for the contingentist is to deny that all possible counter-examples to L have been precluded. Couldn't there be a world in which Coulomb's law is left untouched, but where there is an additional law in place that prevents salt from dissolving in water? Perhaps there is a mysterious force that only acts when an  $\text{NaCl}$  molecule comes in contact with water and overrides the electronegative pull of the water molecule's dipole on the surface of the salt crystal. That Coulomb's law remains the same allows for the existence of the relevant substances, while the extra force ensures that whenever salt comes in contact with water it fails to dissolve.

A general problem with this sort of approach is that it is often motivated by the tacit acceptance of a substantive and contentious view of laws—namely, that they are akin to 'sentences in the book of the world'. This view implies that laws are discreta that can be mixed and matched across possible worlds in any combination that is superficially coherent. This notion of a law is rooted in a Humean conception of lawhood and necessity, though it

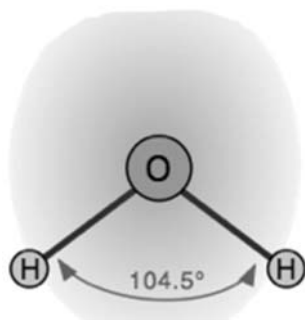


Figure 5: H<sub>2</sub>O's Molecular geometry.

also follows from certain non-Humean conceptions of lawhood, such as Armstrong's [1983]. This understanding of laws is a naïve one, and it is frequently assumed without argument. To simply assume that such a law could exist seems to beg the question against the non-contingentist. But this is not a decisive objection to the proposed counter-example. Upon deeper investigation of what the proposed force would have to look like, however, I think it becomes clear that we ought to be sceptical that such a force could exist in accordance with known physical laws.<sup>24</sup>

There are two ways in which the contingentist could imagine the force to be, in order for it to provide a counter-example to L. The new force could work either by changing or nullifying the force of electrostatic attraction between water dipoles and sodium ions or by leaving the phenomenon of electrostatic attraction untouched and working to overpower some of its effects through additional means. Neither of these assumptions is unproblematic.

In the first route, the contingentist imagines a force that leaves Coulomb's law untouched but nullifies or prevents the force of electrostatic attraction from working as it usually does *only* in instances of electrostatic attraction between water dipoles and sodium ions. The force cannot exercise its power in every instance of electrostatic attraction, or else it will prevent the formation of the ionic bonds that are necessary for the development of a salt crystal. So the force must somehow discriminate between electrostatic attraction that takes place between sodium and chloride ions and electrostatic attraction between sodium ions and water dipoles. Is this the sort of thing that a possible physical force could do?

There is strong reason to think that the answer is 'no.' First, the force would have to act at the scale of the physical (in order to affect electrostatic attraction) yet also be 'upward-looking' enough to respond to differences in molecular structure. Whether or not the force acted at the micro scale on any given instance of electrostatic attraction would be determined by what sort of macroscopic chemical entity contained the electrostatic attraction.

<sup>24</sup>We ask whether such a force could arise given the *actual* laws of physics, because they are what must hold in order for the relevant substances in L to exist.



This is analogous to the suggestion that the magnetic force could be such that the strength of attraction between two magnets could depend on whether or not the magnets in question were kitchen refrigerator magnets. It is not the case that there is a difference at the physical level between electrostatic attraction exerted by a water dipole on a sodium ion and the electrostatic attraction exerted between sodium and chloride ions. At the microphysical scale, the phenomena have all the same physical characteristics—they are instances of the same phenomenon. It is only at a larger spatio-temporal scale that differences emerge, and they are not differences in the character of electrostatic attraction. So a force intended to affect electrostatic attraction in such a way as to limit the relevant changes to cases of dissolution without affecting the structure and stability of the salt and water molecules would not be able to discriminate between the different macrochemical environments that involve electrostatic attraction.

Given that the force must be sensitive to chemical differences, the more promising option for the contingentist is to say that the force arises not at the microphysical scale but at the chemical scale. What would such a force be like? Our understanding of how inter- and intra-molecular forces come about is unified with, and in part stems from, our understanding of underlying physical laws. These include laws in such areas as thermodynamics, spectroscopy, and quantum mechanics. If we want to posit some new chemical force, we need to offer an explanation of how it is to be unified with known physical forces.<sup>25</sup> For instance, in order to accurately describe chemical bonding behaviour, it is necessary to know where the nuclei of the atoms are and how electrons are distributed among them. If we want to suggest that some never-before-seen chemical reaction is possible (in the sense that it is consistent with the underlying physical laws that are required for the existence of the chemical substances in question), we must offer some model showing that the reaction can arise given the relevant physical limitations.

Notice where we have arrived in the dialectic. In this specific case, we have narrowed the question of whether a law of nature is metaphysically contingent to the question of whether some force is nomologically possible given certain underlying laws of physics. This is a surprising result. In order to defend her view, the contingentist must posit the existence of a never-before-seen force that is consistent with already-known physical forces and laws. The nice thing about this challenge is that it is relatively straightforward. Construct a model showing how a chemical force that will prevent the dissolution of salt in water can arise, given the relevant physical restrictions. If the force is to prevent the dissolution of salt in water, we need an account of how the force will arise, what it will be, and how it will be unified with other existing fundamental forces. I can do no better than to make an educated guess about whether the challenge can be met—my suspicion is that, if such a force could consistently arise given our actual underlying laws of physics, we would have seen it already. But whether or not this specific case comes down on the side of the non-contingentist, there are several important lessons to be

<sup>25</sup>This is not to suggest that a chemical force is identical with or reducible to some physical force, nor is it making any claims about entailment, explanatory reduction, or ontological dependence.

learned. We cannot use purely *a priori* methods to investigate the modal status of laws of nature. Given the possibility that the type of necessity outlined in our above case is the rule rather than the exception, we must be cautious about assuming the metaphysical contingency of *ceteris paribus* laws. Perhaps philosophers should take a cue from the way claims about possibility are generally treated in the sciences where the burden of proof is shouldered by those claiming a phenomenon is possible. In this case, the burden of proof has decisively shifted from the non-contingentist to the contingentist.

## 6. Concluding Remarks

It is clear that many forces are at play in determining the structures and behaviours of molecular compounds, and that philosophical questions about the nature of the laws describing them cannot be answered without proper consideration of these facts. It ought to come as no surprise that some knowledge of science must be obtained prior to its philosophical interpretation, and yet many metaphysical accounts of laws, essences, and natural kinds seem to proceed without the requisite understanding. We have good reason to believe that there is far greater interdependence among chemical and physical laws than philosophers frequently assume, and we have shown that the nature of this interdependence can only be discovered through empirical investigation. When evaluating the modal status of the laws of nature, one cannot ignore the relations among them that scientific investigation reveals.

Philosophical investigation stands to gain much insight from a scientific understanding of the relations that laws, substances, and structural properties bear to one another. One outcome of this interdependence is that certain higher-level laws governing the interaction of chemical kinds may turn out to be necessary, as the higher-level laws are determined by lower-level physical ones, and the existence of the substances they govern presuppose these fundamental physical laws. As the natures of chemical kinds are determined in part by their bonding structures, and these bonding structures are made possible by underlying physical laws, any world in which these chemical kinds exist will need to have physical laws quite similar to our own. While the analysis of a specific case does not show the widespread necessity of higher-level laws of nature, it does make plausible the idea that such necessity is more widespread than commonly thought. If we accept that there are certain necessary structural features of salt and water molecules, we ought to accept that other molecules have such properties. If these essential structural features play a role in determining the behaviour of salt and water, we should expect them to do so for other substances as well.

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