

# Chemical Supervenience

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ABSTRACT. This paper surveys some ways in which the chemical realm can be described and outlined in terms of the concept of supervenience. The particular contours of general chemical theory provide a ready basis for interpretation of determination, covariance, and nonreduction—the characteristic metaphysical facets of the supervenience relation—in mutual terms. Building on this, the extent to which chemically-characterized properties and entities can be described in terms of a supervenience-scaffolded structure represents a particularly vivid application that philosophers in general interested in supervenience would do well to attend to. In addition, the model of chemical supervenience given here can be used as a rubric on which to decide on issues already raised by philosophers of chemistry.

The metaphysical relation of *supervenience*—a relation of determination and dependence of one set of properties on another—is one that has received considerable attention by philosophers. It is taken to capture the structure of the material world, and in any discussion of such, the concept is likely to be in use even if not named. Consider the following quotations.

(A1) The structure of a compound can be compared to that of a rope. The kinds of fibers used to make a rope and the way the fibers are intertwined

determine how strong the rope is. Similarly, the atoms in a compound and the way the atoms are arranged determine many of the compound's properties. (Dobson, *et al.*, 2006: 146)

- (A2) It is useful to think of supervenience as belonging to that class of relations, including causation, that have philosophical importance because they represent ways in which objects, properties, facts, events, and the like enter into dependency relationships with one another, creating a system of interconnections that give structure to the world and our experience of it. (Kim, 1993a: 54)
- (B1) [C]olligative properties of solutions are directly proportional to the concentration of solute *particles*. On this basis, it is reasonable to suppose that, at a given concentration, an electrolyte should have a greater effect upon these properties than does a nonelectrolyte.... This reasoning is confirmed experimentally. (Masterson, *et al.*, 1993: 279)
- (B2) [M]ental characteristics are in some sense dependent, or supervenient, on physical characteristics. Such supervenience might be taken to mean that there cannot be two events alike in all physical respects but differing in some mental respect, or that an object cannot alter in some mental respect without altering in some physical respect. (Davidson, 2001: 255)
- (C1) Some properties of the compound individuals that chemists deal with do, in fact, result from mere summation of the properties of the components of those complex particulars. Other properties depend on specific *interactions* between components—whether those compounds are like or unlike—rather than simply on the properties of the components (as individual particulars). (Earley, 2003: 84)
- (C2) Consider mereological supervenience, the thesis that properties of wholes supervene on the properties and relations characterizing their parts.... It

seems likely that mereological supervenience represents a metaphysically fundamental, *sui generis* form of dependence. (Kim, 1993d: 166)

Each of the preceding statements reflect facets of supervenience. A1, B1, and C1 relate specifically to the chemical arena, while A2, B2, and C2 discuss a general philosophical aspect of supervenience itself. Respectively, the pairs A, B, and C address the three basic features of the supervenience relation—*determination* of the supervenient properties by subvenient ones, *covariance* of one set of properties with the other, and *nonsummative difference* in supervenient properties from “subvenient” properties. (That is, the supervenient properties are not, and are not simply additively derivable from, those of the supervenience base. This is also intimately related to the supposed nonreducibility of the supervenient properties to the subvenient; on this point see also Kim (1993c: 140).) Thus, the foregoing is sufficient to demonstrate quite clearly that the philosophical concept of supervenience has ready applicability to the chemical realm. Two of the pioneers of the philosophy of chemistry, of course, suggested this when the discipline was scarcely past its inception (Scerri and McIntyre, 1997: 224–226). What I wish to do in this paper is give a concerted account of the contours of chemical supervenience as such. Purely as an example of supervenience, the ways in which the facets of supervenience are cashed out in chemical theory are strikingly rich and instructive, such that philosophers in general—who thus far have confined the details of supervenience theses to armchair theorizing—would do well to attend to it so as to learn about the ways of actual supervenience in terms of the test case offered by chemistry. Also, the clarifications given here of the nature of chemical supervenience, as such,

should be of help to philosophers of chemistry in sorting out the relationships between chemical properties.

## 1. DETERMINATION AND EXPLANATION

As a person who received a chemical education before receiving a philosophical one, when I first learned the philosophical term *supervenience*, I had the experience of learning a word for a concept I already possessed. It seems reasonable, in fact, to think that anyone capable of teaching or practicing chemistry possesses a robust concept of supervenience although the vast majority of such will have never heard the word. In chemistry texts, one finds ubiquitous discussion of relationships between characteristic sets of properties in terms of determination and explanation, based on particular kinds of mereological interactions. Implicit in such explanations is a picture of layered, stratified families of properties linked by upward determination—and conversely, downward dependence—relationships.

Such stuff is the very pith of a supervenience-based model of the world, which analytic philosophers of the last 25 years or so have tended to cleave to in some form or another, but in more of a broadly schematic sense than that of offering fleshed-out, particularized theories. When one surveys the philosophical work on supervenience that has been done, it becomes apparent that the preponderance of it has been along the lines of how supervenience theses might be formulated given certain formal parameters and other desiderata, rather than actually proffering supervenience-based metaphysical theories, as such. On the other hand, the whole edifice of properly chemical characterization might be said to be a single grand concrete supervenience thesis, albeit without the name. In the face of this state of affairs, one can only conclude that each set

of minds, the one philosophical and the other chemical, would benefit greatly from a meeting in the middle and a comparing of notes. However, as it turns out, philosophers by and large seem as little interested in the chemical details of the construction of the physical world as the large majority of academic chemists are in the philosophical contours of the metaphysical picture that captures the features of the realm in which *they* work.<sup>1</sup> So much the better, then, that there is a place for such explorations in the philosophy of chemistry.

When the notion of *explanation* finds mention in the extant philosophical literature on supervenience, it is usually along the lines of noting that a supervenience thesis that makes use of the usual theoretic materials cannot in itself do any explanatory work. What such discussions immediately suggest by their mere presence is that supervenience itself is the kind of consistent feature of the world that immediately cries out for explanation. The typical philosophical application of supervenience is to the philosophy of mind and the question of physicalism, and therefore to the relationship between mental and physical properties; linking explanations between such families of properties are notoriously absent or obscure. So, naturally, the notion that is widely abroad about explanation *vis-à-vis* supervenience seems to be that it is highly desirable with respect to it, but conspicuously missing in light of it.

Meanwhile, the nature of chemical explanation turns out to be just such a thing that philosophers have wanted for their own formulations of supervenience. Moreover, explanation in chemistry is intimately wedded to the notion of determination; indeed,

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<sup>1</sup> With certain exceptions, perhaps most notable among which are a number of regular contributors to this journal who are themselves members of academic chemistry departments!

what immediately suggests itself is the question of which came first in the arena of chemical theory. A first approximation as to the nature of their relationship would be to say that explanation is the epistemological or theoretic side to a coin of which the flipside is metaphysical determination. With a prior concept of determination borrowed from other arenas, it seems likely that explanation was first invoked in terms of such. I would go on to suggest that after that, the two became bound in chemical metatheory by extensive use fostered by certain forms of causal and analogizing-like reasoning (see A1, above, for an example of a description of chemical determination in such language as clearly points to explanation).<sup>2</sup> What has been commonplace in chemical theory for some time is the consistent working assumption that theoretically-propounded (subvenient) properties determine already-known (supervenient) properties, and that the unifying theory will *explain* such determination. For example, as one college chemistry textbook says, “[w]hat a theory of covalent bonding should do is help us understand *why* a given molecule has its particular set of observed properties—bond dissociation energies, bond lengths, bond angles, ...” (Petrucci, *et al.*, 1993: 402) (my emphasis).

If supervenience is metaphysically real and not merely epistemological, then philosophers of mind interested in applications of supervenience may learn some valuable lessons from chemical supervenience about the possibilities in physically-grounded supervenience in general. Chemical supervenience is robustly explainable in terms of chemical theory, so what it actually seems to be is a case of what Terence Horgan has called *superdupervenience*, which is supervenience that meets this

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<sup>2</sup> Admittedly, this is but conjecture, and I would certainly welcome any correction on it based on empirical studies done by others.

condition: “Any genuinely physicalist metaphysics should countenance ontological inter-level supervenience connections only if they are robustly explainable in a physicalistically acceptable way.” (Horgan, 1993: 563) With the assumption that it is essentially the same type of relation being appealed to in both arenas, some analogy between the supervenience of water on  $H_2O$ <sup>3</sup> on the one hand and that of mind on brain might well be in order. One obstacle to supervenience theories of mind has been that there is an “explanatory gap” between mental and physical properties: there is said to be a failure of one to “logically supervene” on the other (Chalmers, 1996: 106–108). But although explanatory theories can be adduced in other arenas of supervenient relations, it should not be considered surprising that in the case of the mental and the physical there is an explanatory gap: the water- $H_2O$ /mind-brain analogy seems to fail, but only because in the mind-brain case, the supervenient properties are the very ones that would be *doing* the explanation! So what David Chalmers refers to as “failure of logical supervenience” of the mental on the physical may well be simply because the usual epistemological side of the supervenience thesis cannot be filled out in this uniquely self-referential case.<sup>4 5</sup> With this hurdle cleared, it is a short step to the supposition that,

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<sup>3</sup> Philosophers of chemistry have been generally subtle enough in their distinctions to say that the relationship between “water” and molecules of  $H_2O$  is at least other than identity (see Simonian (2005) and Weisberg (2006), for recent examples); a more detailed characterization of the relationship as a characteristically supervenience-based one will follow in §2. See also Johnston 1997 for an extended defense, from a phenomenological point of view, of a “constitution” view of manifest kinds’ relation to their chemical constituents, which I fully endorse as an obverse consequence of the supervenience view offered here.

<sup>4</sup> Tye (1999) has actually come to a very similar conclusion.

given the example of chemical supervenience, all physically-grounded supervenience is superdupervenience, and hence “zombies” (physical duplicates of human beings but with no conscious experiences; see *ibid.*, 94–95) are as metaphysically impossible as it is for H<sub>2</sub>O molecules not to constitute water at atmospheric pressure and between 0 °C–100 °C. (But also—as Chalmers holds in the case of mind and brain—the relation will not be a strictly *reductive* one, as I will argue in the next section.)

Also based on the example of chemical supervenience, it seems that determination is the metaphysical root of supervenience itself, while covariance would follow from determination and not vice versa. However, if anything, covariance is the factor that has for philosophers come to be emblematic as the *sine qua non* of a supervenience relation. For example, consider the following, from Jaegwon Kim (whose writings on supervenience are almost certainly the most influential in this department of metaphysics), after having briefly canvassed the basic components to supervenience—covariance, dependency, and nonreducibility:

Obviously, covariance is the crucial component; any supervenience concept must include this condition in some form. The main issue, then, concerns the relationship between covariance and the other two components, and here there are two principal questions. First, can covariance yield dependence, or must dependence be considered an independent component of supervenience? Second, is there an interpretation of covariance that is strong enough to sustain supervenience as a dependency relation but weak enough not to imply

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<sup>5</sup> Actually, that supervenience should be at all amenable to “explanation” is a very interesting fact about our relationship to the world in which we find ourselves; it is one that is not at all inevitable given just supervenience-based facts themselves about the world around us, and a point that goes ubiquitously unremarked and taken for granted.

reducibility? More broadly, there is this question: In what ways can these three desiderata be combined to yield coherent and philosophically interesting concepts of supervenience? (Kim, 1993c: 140)

The apparent explanation for the centrality of attention covariance receives is that covariance is the initial observable factor in a supervenience relationship, *provided that the supervenient and subvenient properties are each independently observable*. This proviso holds for realms of traditional philosophical interest in which supervenience plays a crucial role, such as the already-mentioned mental/physical dyad, and also the supervenience of ethical facts on nonethical facts pressed upon by such as G.E. Moore and R.M. Hare (see Kim, 1993c: 136–138 for a brief survey), but not so in the case of chemical supervenience. For, as has been suggested, upon a chemical discovery that leads to a completely novel theoretical postulate, determination and explanation are invoked almost hand-in-hand, from which covariance obviously follows in their train. Therefore, in the case of chemical supervenience, no one would think to take covariance as its most fundamental feature. This reflects a much more sensible interpretation of supervenience in general, it seems to me, than one that would take covariance as metaphysically primitive, from which determination and nonreduction would supposedly follow. For covariance of families of properties to be the brute fact from which other supervenience facts follow seems to me to be quite a mysterious notion, and it is remarkable that that notion initially came to be the standard rubric through which supervenience is interpreted.<sup>6</sup> The baseline Kimian requirement that all other features of

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<sup>6</sup> Interestingly, Kim (*ibid.*, 143–148) recognizes that dependence (determination) must be metaphysically prior to covariance, yet still insists that the requirements of dependency and covariance be considered separately, and that dependence, in a final

a supervenience relation be defined logically in terms of covariance is part and parcel of the common assumption that supervenience is inherently inexplicable and can only be explored *ex post facto*, as it were, from the philosopher's armchair. But in the case of chemical supervenience, at least, the relation can be approached from "inside," in a fully explanatory sense.

## 2. ON (NON)REDUCTION

The fact that varieties of properties from the manifest to the physical that are tied together by supervenience relations (as already discussed; see also Earley 2003, who all but mentions supervenience by name) can also be tied together in terms of chemical explanation raises the question of ontological reducibility: are the distinctively chemical, and then also phenomenally manifest, properties to be understood as ontologically reducible to combinations of basic physical properties (that is, those described by physics proper)? Philosophers of chemistry have not at all shirked the exploration of this most interesting question.

Of course, the question of nonreduction in general is also closely tied to the concept of supervenience. To illustrate, D. M. Armstrong's nonstandard use of the term *supervenience* serves as an exception that proves the rule, given that he applies it to unrestricted mereological *fusions* of parts, which, given the parts, come as an "ontological free lunch": in this scheme, "[w]hat supervenes is no addition of being,"

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analysis, needs to be formulated in terms of covariance!—"What must be added to covariance to yield dependence is an interesting, and metaphysically deep, question." (*ibid.*, 148) Counter to that, I would suggest that following the example of chemical determination and explanation, the nature of the covariance should be counterfactually defined in terms of the nature of the dependence, and not the other way around.

and “the supervenient is ontologically nothing more than its base.” (Armstrong, 1997: 12, 13) What is more or less standard practice, on the other hand, is to consider supervenient properties as *other than* those upon which they supervene. What is somewhat more controversial is whether supervenience—under its standard physicalist formulations—could, in principle, be considered a nonreductive concept. In this section, the character of chemical supervenience will be examined in terms of its potential to yield some form of nonreductive supervenience thesis.

First, whence chemical supervenience, specifically? The generation of supervenient properties from subvenient ones that is so characteristic of the subject of chemical studies arises as a result of an interaction of parts that takes place when such parts are in a certain configuration. The kind of mereology this calls for is quite different from the widely-assumed extensional interpretation of classical mereology, in which any parts whatever automatically compose some whole, regardless of their relations to each other. As Joe Earley has said, “[a]n adequate theory of wholes and parts (mereology) must take into account that when individuals enter combinations of interesting sorts they no longer are the very same individuals that existed prior to the composition. It appears that no such formal theory now *actually* exists.” (Earley, 2005: 85) However, interestingly enough, such has been at least alluded to by none other than Jaegwon Kim, and without chemistry obviously in mind: “One interesting application of the supervenience concept is mereological supervenience, the doctrine that the character of a whole is supervenient on the properties and relationships holding for its parts. This apparently calls for two distinct domains: one domain consisting of wholes and another consisting of their parts. It would be of interest to know how a dependency relation can

be formulated across two domains.” (Kim, 1993b: 113) This sounds just like the distinctively chemical supervenience understood by anyone familiar with the rudiments of chemical bonding theory: atoms interact in their electronic properties, when those atoms are in a certain relation to each other, to form second-order molecular properties that are rooted in, yet distinct from, those of the atoms themselves. In terms of the multiple-domain kind of supervenience described by Kim, molecular properties can be understood as belonging to a separate, supervenient domain from that of their subvenient atomic constituents. Likewise, properties of atoms themselves could be considered to belong to a domain supervenient on those of subatomic particles taken individually. Going the other direction from molecules, particular kinds of characteristic molecular interactions could be considered as giving rise to another domain of supervenient properties, these falling into the phenomenally-recognizable class. So, multiple-domain supervenience seems to me to be an ideal philosophical model for fully-ramified representations of chemical systems. Thus, liquid water supervenes on any collocation of H<sub>2</sub>O molecules that falls within a certain range of mean kinetic energy. Furthermore, there are grounds for taking these supervenient properties as ontologically real and not merely heuristic “theoretical entities.” For example, as Vollmer has suggested (2003), if the “secondary” (supervenient) properties are supposed to be dependent on observational conditions and not independently existent, there would be no bar to suggesting that, since they depend on “primary” (subvenient) properties, the primary properties would have to be similarly ontologically suspect too: therefore, there is good reason to think that distinct supervenient properties are as real as those that are subvenient to them.<sup>7</sup>

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<sup>7</sup> See also Markosian (2005), who makes a good case that the conjunction of what he

Now, if we think of chemically supervenient properties as distinct from those of preexisting parts taken individually, what room is left to us for “reduction” of entities that fall in the chemical class to the properties of elementary particles as described by physics? To begin with, consider Armstrongian supervenience: in these cases, the whole simply “is” the parts, taken in singular as a mereological fusion. This kind of relation is certainly one in which the “supervenient” entity is reducible to its parts. However, as was discussed earlier, chemical properties per se are not simply summations of physical properties of particles.<sup>8</sup> Are these kinds of properties reducible? As an example of a maximally weak criterion for reducibility, G. K. Vemulapalli has said: “In my use of the word [*reduction*], if a property of the whole is shown to be a necessary consequence of parts having certain properties, then that property of the whole will be said to be reduced to properties of the parts.” (Vemulapalli, 2003: 91) But this seems to leave us with a stark choice between reduction on the one hand and inexplicable brute-fact emergence (in the British-Emergentist sense; see Broad, 1999, and also discussed in §4 below) on the other as the only choices. In fact, on that criterion any strong supervenience would automatically entail “reduction,” and this is, on the face of it, a conclusion that would

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calls the Hierarchy Thesis (which involves supervenience) and Mereological Atomism does not entail “Ontological Fundamentalism”—the thesis that only the base properties of a thing are maximally real.

<sup>8</sup> One particularly vivid illustration of this is given by any graph showing periodic trends for a particular atomic property—*e.g.*, electronegativity, atomic radius, etc.—as a function of atomic number. Given an arithmetical increase in number of protons and electrons, even within the filling of a single *d* shell, say, the change in atomic radius is not only not linear, but seemingly unpredictable from one element to another, although on larger scales enough regularities are manifested to reveal periodic trends.

require specific argument rather than to result as a matter of definition.<sup>9</sup>

As discussed in §1 and elaborated on above, chemical properties are distinguished by their close explanatory link to physical properties “downward,” and to phenomenal properties “upward.” The exhaustiveness of the explanatory characterizations afforded by chemical supervenience shows it to be more a flavor of “superdupervenience” than most varieties of supervenience considered by philosophers. Of course, any reductionist thesis at least requires supervenience, but the converse does not directly follow. If we consider a relation as obviously reductionistic as Armstrongian supervenience as not at all interesting or explanatory but simply brutal, then it is plausible to consider that the more strongly explanatory the connections are between supervenient domains, the stronger the case becomes for the objective ontological reality of *each* domain. However, care must be taken in characterizing the ontological scheme reflected in chemical characterizations and expressed in terms of supervenience: Lombardi and Labarca (2005) have argued in a recent paper for the “ontological autonomy” of the chemical realm; the spirit is one of nonreduction and with which I quite agree, but given that the relation to be characterized is one of dependence and strong supervenience, “ontological autonomy” seems to be the wrong phrase to use. Explanatory dependence cuts both ways, ontologically: neither domain of properties so situated can occur without the other. Any “autonomy,” strictly speaking, of chemistry per se is just pragmatic: chemical entities may be handled in practice without recourse to physical characterization, but only bereft of any further “downward” explanation. A

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<sup>9</sup> In personal communication, Vemulapalli agrees that the quoted statement stands in need of revision.

complete *ontological* account of what is going on in any given chemical system cannot but include the existence of the physical entities on which the chemical ones depend; so, given chemical supervenience, chemical entities must be considered real and uneliminable, but definitely *not* ontologically “autonomous.”

An additional point is worth making on the particular *mereological* character of chemical supervenience. Considering a chemical whole—say, a benzene molecule—as dependent, and hence strongly supervenient, on its parts, the question of whether it is “reducible” to such parts can be taken in either of two ways: is it being asked whether such an entity is definable in an additive sense in terms of its parts *taken separately*, or do we want to know if it is capturable in terms of a straight characterization of the parts *so collocated*? (The reason the question of reduction comes apart into these two versions is because of the nonstandard mereology, already mentioned above, involved in chemical interactions: parts undergo changes when they form a whole.) To the former version of the mereological reduction question, the answer is No, as has been stated. To the latter question, the answer seems to be Yes, and it is just this sort of part-whole relation that is at the root of chemical supervenience. As Vemulapalli (*ibid.*) points out, the quantum state of a molecule can be obtained by superposition of the states of the constituent atoms of the molecule. But the combined molecular state is unique to begin with, and results only from changes, undergone during bond formation, in the electronic states of atoms. It is precisely because of the fact that an entity with a single quantum state of its own is constituted from the bonding of six carbon and six hydrogen atoms that a *bona fide* whole rather than simply a fusion of parts (for those of us less than enamored with unrestricted mereology) is constituted in this interaction. Properties of

the parts, so constituted, exhaustively determine those of the whole, so this a textbook case of mereological, and by the same token chemical, supervenience. But the only sense in which the whole is “reducible” to the parts is perhaps only by Vemulapalli’s maximally weak criterion of not being a case of inexplicable emergence. In a benzene molecule, the subvenient parts—carbon and hydrogen atoms—are still there, and so is the whole, which cannot exist without the particular configuration in which the parts combine. In this sense, chemical-mereological supervenience seems to me to represent as much as one could ask for in a nonreductive case of supervenience.<sup>10</sup>

### 3. CLOSURE AND INTENSIVITY

As to the character of these domains and the relations between them, it is certainly not a case of one-to-one relations of dependence and determination between properties. As Jaegwon Kim has said, “[i]t is...clear that supervenience is better thought of as a relation not between properties or terms taken singly but between *sets* or *families* of them.” (Kim, 1993a: 55) Chemical supervenience needs to be captured in a holistic sense, in terms of each complete domain as well as the multiple-domain structure as a

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<sup>10</sup> For more on how the quantum picture of superposition in bonding yields nonreductive supervenience, see the very interesting discussion of Redhead (1995: 54–62, esp. 60–62). In summary, there are vectors in composite atomic Hilbert spaces that “cannot themselves be represented as the tensor product of vectors in  $H_1$  and  $H_2$  respectively, but only as superpositions of such tensor products.” (60) “So the part-whole reduction has failed in the sense that there exist perfectly good properties of composite systems which [sic] do not supervene on any properties of the constituent systems” (61) (taken separately, I presume Redhead means). “The reductive hierarchy founding the whole of science on the properties of individual elementary particles is thus shown to be mistaken.” (62)

whole. What is needed, in other words, is a *closure* principle by which to delineate each supervenience domain. This is a standard requirement, discussed in the philosophical literature, of a supervenience thesis (for example, see (Van Cleve, 1990)). With respect to chemical supervenience, there is a distinctive closure principle to hand for each domain. In the case of molecules, there is *electronic closure*, discussed by Earley (2000), and one might similarly characterize the formation of atoms from their constituents as nuclear-quantum closure, and that of macro-level bodies such as an ice cube by intermolecular closure. Chemical closure principles differ from the usual kinds of property-forming closure principles discussed by philosophers, which are along the lines of closure under logical Boolean operations, entailment, and so forth. What actual chemical closure principles provide is generation of distinct chemical properties via intrinsic potentialities already present in the components. Such closure may also be valid under certain applications of the formal and logical principles discussed in philosophy, but is physically inherent in causal powers of chemical properties themselves and thus prior to such formal closure principles.

The characterization of chemical properties as distinctively belonging to separate supervenience domains is a powerful rubric that can be used to decide on some issues already broached by philosophers of chemistry. In Paul Needham's "Chemical Substances and Intensive Properties" (2003), for example, he aims to characterize chemical mereological relationships with a view to recognizing both the "continuous" nature of macro-level "substances" as well as the chemical atomism that underlies it according to the modern conception. What emerges is a scheme of substance properties that are intensive but not homogeneous, whereas phase properties are considered both

intensive and homogeneous; this is allowed by a conception of spatial cooccupancy borrowed from the ancient Stoics (see Needham 2002). Thus,

[t]he salt in a brine solution occupies the same place as the brine. ... [S]ome of the parts of the region occupied by the salt are parts of the region occupied by the water in the brine; but the salt and water are separate, and so the parts of the salt in question are not parts of the water. (Needham, 2003: 107)

I find such results very counterintuitive, to say the least, if not incoherent: one would certainly want to say that in a brine solution the region occupied by the salt is a proper part of the region occupied by the brine, not that they occupy exactly the same region;<sup>11</sup> to begin with, where would this leave the water? Fortunately, the picture of chemical supervenience that has been given thus far provides an alternative conception, one that does not require distinct intradomain entities to occupy the same space. “Salt” in a brine solution—dissociated sodium and chloride ions—associate with H<sub>2</sub>O molecules in such a way that the intermolecular/interionic interactions amount to a property closure generating a supervenient domain of phenomenal macro-level properties of the brine solution. There is co-location of the supervenient domain on the subvenient one, but in such a way as overlapping of intradomain moieties is disallowed, unlike in Needham’s theory. Also, according to the present theory, solution properties are in fact intensive (as are other substance properties), *pace* Needham. The classifications of intensivity and homogeneity need not come apart according to the

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<sup>11</sup> In personal communication, Needham confirmed that this is, in fact, what he means to say.

present theory—indeed, they are unified by closure principles characteristic of a domain—which intuitively is as it should be, I think.

The flipside to that coin, however, is that the stratification of properties into domains requires that, strictly speaking, water shares *no* properties in common with H<sub>2</sub>O (although they are unified in a supervenience relation with at least nomological necessity). This may seem counterintuitive in itself, but it is only the result of clarifying the place of each entity's properties in their proper domains in relation to subvenient and supervenient properties according to chemical theory, thus providing a systematic framework on which to eliminate confusions that come out of ambiguous terminological usages. And I do see chemists as constantly using element and substance words in ways that are *prima facie* ambiguous, although disambiguated by context, which is itself understood according to the implicit working notion of chemical supervenience that I contend that all chemists possess. For example, names of elements, such as “oxygen,” are used to denote atoms of the element and also molecules entirely consisting of atoms of the element.<sup>12</sup> (Other, similar, examples are given by Needham (2005: 111–112), although the lesson he draws from them of course differs from the account given here.)

Needham's conception was also challenged by Joe Earley (2005), who contends that such classically-based mereology leaves out the crucial point that chemical entities undergo changes when they combine in ways that affect or effect substance properties. Earley's view, which includes the idea that “there is no salt in the sea,” accords squarely with the present theory of the nature of chemical supervenience: *salt* is the solid crystal

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<sup>12</sup> This implicit ambiguity, I think, explains the persistently reoccurrent question of nonchemists: “If water contains oxygen, why doesn't it feed fires instead of putting them out?”

constituted by the sodium chloride lattice structure, and this is not present in brine. Salt's subvenient parts—sodium ions and chloride ions—are still present in brine, but their solvation by H<sub>2</sub>O molecules makes for electronic differences in the ions themselves between the two cases of salt and brine. The disagreement between Needham and Earley on this issue can thus be framed at least partly as a verbal one: Needham's contention is correct if "salt" is taken in the ambiguous and inclusive sense of either solid sodium chloride crystals or sodium and chloride ions solvated in solution but taken in sum; Earley's usage of "salt" as strictly of the crystalline species is in accordance with, and clarified by, the present theory.

Earley's own statements in his (2005) supplemented with the present supervenience theory provide the materials for an effective reply to Needham's (2005) rejoinder to Earley. Although for the sake of space I will not go into too much detail, I will give an example of the sort of suggestion that could be made. First, Needham:

Joe points out that sodium cations and chloride anions "seriously perturb the structure of solvent water", although I'm not sure whether he really wants to say that there is no water in seawater in addition to saying that there is no salt.

(Needham, 2005: 114)

To this, the reply can be made that Yes, in fact, "there is no water in seawater," because although there is H<sub>2</sub>O in seawater, H<sub>2</sub>O ≠ water. And, of course, seawater is not water except perhaps in a rough species/genus sense.

#### 4. SUPERVENIENCE OR EMERGENCE?

To take stock on what has been said so far, how should we characterize chemical supervenience in terms of the broad scope of supervenience theories already suggested

by philosophers? In contemporary philosophical discussions of supervenience, it has often been difficult to tell the specific nature of the supervenience concept being appealed to, or analyzed as a definiendum; it can, indeed, fall anywhere between and inclusive of Armstrongian supervenience and what falls under the heading of “emergence.” The early-20th-century school of thought known as British Emergentism, examples of which include C.D. Broad and Lloyd Morgan, characteristically held that certain levels of properties emerged from certain organizations of preexisting ones in lawlike ways, albeit with an intrinsic absence of prior predictability. This last unpredictability clause is the distinctive one for emergentism, and it is one that conspicuously does not apply to the chemical supervenience relations discussed here: there is no reason to think, and every reason not to think, that given exhaustive knowledge of properties of the preexisting chemical parts taken separately, C.D. Broad’s “mathematical archangel” (Broad, 1999: 498) would not be able to deduce the fact that chemical supervenience would occur and the full nature of the supervenient properties themselves. (This goes counter to what Broad said specifically about chemical entities, in fact: see pp. 495–6, *ibid*. I suspect that most contemporary chemists will find what Broad had to say about the unpredictability of molecular properties from atomic properties per se to be somewhat odd.) This is precisely because of the nature of chemical explanation itself, which from one perspective might be taken to describe exactly how supervenient properties could be predicted if, conversely to the actual process of discovery, properties of the separate chemical parts were exhaustively known first.

Yet chemical supervenience seems to fall into the category of what some philosophers have considered “emergence.” For example, G. K. Vemulapalli: “If by emergence, we mean manifestation of any property in the whole that has no qualitative analog in the parts, molecules provide examples of emergence.” (Vemulapalli, 2003: 93) And chemical supervenience exactly fits a definition of emergence given by a philosopher not treating specifically of chemistry: “If  $P$  is a property of  $w$ , then  $P$  is emergent if and only if (1)  $P$  supervenes with nomological necessity, but not with logical necessity, on properties the parts of  $w$  have taken separately or in other combinations; and (2) some of the supervenience principles linking properties of the parts of  $w$  with  $w$ 's having  $P$  are fundamental laws.” (McLaughlin, 1997: 39) Not only are chemical properties “emergent” in such lights, they are also superdupervenient! So, in general terms, chemical supervenience falls into a very interesting and perhaps novel classification of supervenience, in that it turns out to be more similar to emergence than how many philosophers have thought of supervenience, but provides a robust stratification of properties united by exhaustive theoretical explanation.

##### 5. SUPERVENIENCE AND ARISTOTELIAN SUBSTANCE THEORY

Finally, I wish to make a suggestion about the significance of chemical supervenience with respect to Aristotelian substance theory, which in itself has already been of interest to philosophers of chemistry (see, for example, Needham (2006)). Aristotle is widely taken to have anticipated, largely in his own “chemistry” he elucidated in his *On Generation and Corruption*, some aspects of modern chemical concepts. Although he rejected atomism, the conception of *potential presence* and *actual presence* required by his theory of mixtures is of special interest here. Aristotle held that

[i]n one sense things come-to-be out of that which has no ‘being’ without qualification: yet in another sense they come-to-be always out of what ‘is’. For coming-to-be necessarily implies the pre-existence of something which potentially ‘is’, but actually ‘is not’; and this something is spoken of both as ‘being’ and as ‘not-being’. (*On Generation and Corruption*, I:3; all quotations are from the Joachim translation)

His rejection of atomism seems to have turned on (1) the seeming inability of atomism to account for continuity, and limitless divisibility in principle, of substances, and (2) its inability to explain the possibility of change (see *On Generation and Corruption* I:2, and the discussion in Needham (2006: §2)). Aristotle gives atomism, as put forward by its proponents Democritus and Leucippus, a fair treatment, ascribing the following arguments to them.

Democritus and Leucippus...postulate the ‘figures,’ and make ‘alteration’ and coming-to-be result from them. They explain coming-to-be and passing-away by their ‘dissociation’ and ‘association,’ but ‘alteration’ by their ‘grouping’ and ‘position.’ And since they thought that the ‘truth lay in the appearance, and the appearances are conflicting and infinitely many,’ they made the ‘figures’ infinite in number. Hence—owing to the changes of the compound—the same thing seems different and conflicting to different people: it is ‘transposed’ by a small additional ingredient, and appears utterly other by the ‘transposition’ of a single constituent. For Tragedy and Comedy are both composed of the same letters. (*On Generation and Corruption*: I:2)

What I propose is that—given Aristotle’s recognition of this atomistic explanation of composition and change and his reasons for rejecting atomism—if he had possessed a concept of supervenience like the chemical supervenience discussed in the

present paper, he would have had no apparent reasons to reject atomism. For, the atomistic explanation quoted above (minus the “figures” being “infinite in number”), supplemented by the present theory of chemical supervenience, is quite like what we should say in terms of present chemical theory. Homogeneity and intensivity inheres in the top supervenient domain of a thing, although it is, according to the present theory, *constituted* by atoms. And, chemical change is explained by the recombination of atoms, upon which supervenes the fundamental differences between chemically constituted substances—for example, compare O<sub>2</sub> and O<sub>3</sub>: the addition of an extra oxygen atom to O<sub>2</sub> does not make for a simple arithmetical difference some property, but a complete qualitative difference in properties. The properties of an oxygen molecule are present potentially in each oxygen atom taken separately, but such properties are not the actual properties of each separate oxygen atom, *until* they are so combined. But the “possibility” for Aristotle to have had a supervenience concept anything like that of chemical supervenience can only, I think, be considered in a *per impossibile* sense, because given the unique power of modern science to discover supervenience relationships like those exemplified in the chemical realm, without the aid of the methods of modern science Aristotle can scarcely be expected to have dreamed of what the structure of the physical world is actually like.

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