Chapter 4

Who's Afraid of Reductionism's Wolf? The Return of Scientia

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Science is an answer to a question that precedes it

(Sergei Bulgakov)[1]

'Knowledge also is surely one, but each part of it that commands a certain field is marked off and given a special name proper to itself. Hence language recognizes many arts and many forms of knowledge.'

(Plato)[2]

Introduction

This chapter argues several mutually reinforcing points, many of which lead to the conclusion that both scientism and reductionism are false. The temptation to indulge such erroneous philosophical positions arises from our bewitchment by a picture of a hierarchical view of the sciences, with physics being the master science. Physics is that which is really real (ontas onta), to echo Plato, while all others pale into various degrees of insignificance. This is the idea of the layer cake. Such a highly misleading picture itself rests on a fiction; that of a base. From the pre-Socratics to now, this perennial temptation takes on many forms, whether it be Thales' water, Democritus' atom, Dawkins' DNA, the Brain, or physics and the 'particulate'. In short, I argue that there is no base (except that of *methexis*), no fundamental level that would afford the fundamentalism of a grand science, concomitantly accommodating reduction to that science's base element or currency, so to speak.

1. Bulgakov 2000, 170.

2. *Sophist*, 257c. Aristotle in *On the Heavens* echoes this, as does Aquinas in his *Commentary on Boethius' De Trinitate*, wherein he, like his forebears, argues for an alethic monism, but one that is intrinsically pluralist.

The above critique is bolstered by two central arguments. Philosophy tends to operate in the opposite direction from physics, especially when it comes to reduction and theory construction. Consequently, many philosophical problems, such as supervenience or causal inheritance, are wrongheaded, if not old fashioned. Furthermore, the temptation for reductionism should be resisted; yes, but reduction itself should not be feared: While emergence is most certainly prevalent, but it is not *always* preferable, and can at times act as nothing but a placeholder. Likewise, bottom-up causation versus top-down causation are not to be set in strict opposition. The relation between the micro and macro is not asymmetrical, as there is no base on which they sit. At times the macro is in charge, while at other times the micro is (by micro we mean the primitive subvenient material base, for example, the particulate). The relation can be symmetrical, no doubt, as the micro is often beholden to the macro, yet the macro can also be beholden to the micro, indeed it can even be a 'part' of the micro (see below). The whole may well indeed be more than its parts, being so because it is different than its parts, but that is only very significant for the advocate of reductionism. Lastly, mechanism is not necessarily in opposition to the non-mechanistic, or reductionist and anti-reductionists, in short, we need both.[3] The chapter's conclusion is that scientific ontology is plural, not to mention its epistemologies, all of which are beholden to an alethic monism, metaphysically speaking. All *scientia* involves, without doubt, an apophatic and a cataphatic moment: we posit a primitive term, doing so with trust; but in so doing we know we fail to capture.

Divorce Cake – Scientism and Reductionism

The origin of the division of the sciences into isolated fiefdoms which are self-governed is a very modern idea, which can be traced back to the juridical model of the sciences that emerged in the thought of Bartolo da Saasoferrato in the fourteenth century, and was later formulated in more explicit terms by Jean Bodin in 1576, wherein separate sciences lived under the organizing principle that *superiorem non recognoscens* – each science does not recognize any superior authority. This way lay autonomy, a sort of aseity. It was presumed that the sciences consisted in a layer cake, to borrow Putnam and Oppenheim's metaphor from the 1950s. Under the sway of this image reductionism and its sibling scientism were

3. For example, in relation to cancer we adopt a cell-based approach which involves reduction, namely, somatic mutation theory. At the same time, we must adopt a tissue-based approach which is more about carcinogenesis, namely, tissue organization field theory (see Bertolaso 2016). Similarly, in nuclear physics we have two models, namely the nuclear shell model and the liquid drop model. The latter treats the nucleus as an incompressible drop of nuclear fluid, and this does not afford mechanistic explanation, while the former does insofar as the nucleus is approached in terms of energy levels. Both are to be employed.

born.[4] Science is the only begetter of truth (first step), but in truth all sciences were to be reduced to one master science, physics (second step). Yet these two steps leave science vulnerable. As van Fraassen asks, 'Can we divide our language into a theoretical and non-theoretical part? … All our language is thoroughly theory-infected' (van Fraassen 1980, 12). The precarious nature of all theorizing, including that of the sciences, comes immediately to our attention when theories change, especially in the case of *radical theory change* (we need to only think about the move from Newtonian physics to Einstein's special and then general relativity (GR), or the shift from classical to quantum mechanics), which is evidence of 'the transience of our best accepted theories' (Sklar 2010, 1122). Hence we can speak of *theories emeritus*. What was taken to be obvious turns out not to have been the case. This is sometimes referred to as 'meta-pessimistic induction': things we took as settled in science changed, therefore science never rests on a permanent ground. In short, we must *not* base our philosophies on what, for example, current physics says (or indeed any science), extrapolating philosophical conclusions from such a ground without knowing what future physics will tell us (Hempel's dilemma), *and* we must not fall into the trap of thinking that qualitative, *radical theoretical change* is over, as so many under the sway of Newtonian physics once thought. In this way the claim for a 'base' to the layer cake is truly undermined: Science is, to paraphrase Poincaré, ruins accumulated upon ruins.

In 1949 Ernst Nagel published his understanding of what reduction entailed, made famous later (though unchanged) in his 1967 book (see Nagel 1949; 1967). According to Nagel, reduction was a matter of intertheoretic explanation, which is to say, the reduced theory is explained by the reducing theory: explanation being understood in deductive-nomological terms (and its extensional equivalence), which is in the end a degenerate form of statistical explanation (see Wimsatt 1979). Reductions were either homogeneous, such as the reduction of Galilean laws of falling bodies to Newtonian mechanics (Nagel 1967). Or they were heterogenous, for example, temperature being reduced to statistical mechanics. Generally, Nagel argued for two requirements for reduction: connectability and derivability. In truth, as Sklar pointed out in 1967 (and Nickles soon after confirmed his findings) this is naive from a historical point of view. The number of actual cases in the history of science where a genuine homogeneous reduction takes place are very few and far between, and as for heterogenous, they are just as problematic, most of the time. Indeed, below we will address the example just provided, demonstrating its failure (Sklar 1967; Nickles). Important here, however, are the philosophical implications of such reductionism. Scientism, but not *scientia*, faces the following charge: All sciences *Vicissim omnes ab omnibus repelluntur* ('all is in turn refuted by all') to quote Jean Bodin from his *Colloquium Heptaplomores* (1593). The sciences are very high forms of art, no doubt, art that necessarily involves interpretation. But 'it is crucial to observe that the demand for interpretation arises within theoretical

4. The term 'reductionism' first appears in Garnett (1942). Scientism appears to have been first used by Friedrich Hayek.

science. It isn't something imposed on the scientist by some aprioristic philosopher' (Sklar 2010, 1123). The Quine–Duhem thesis that theories are underdetermined by the evidence should be the bedtime story of every fundamentalist. After all, we've more than thirty theories of the atom. It should be recalled that soon after Paul Dirac published his relativistic wave equations for the electron in 1928, Max Born declared that 'physics, as we know it, will be over in six months'. Blushes all round, back then at least. But not in 1980 for Hawking who this time proposed that Gauge Field Programme would be the end of the story (see Hawking). Today we have several candidates: String theory; M-Theory, the ADS/CFT correspondence (also called the 'holographic conjecture').

In physics the rise of the standard model (SM – electroweak theory and quantum chromodynamics) in the 1970s and 1980s was interpreted as a major success for reductionism, that is, the move to a 'final theory', forgetting that even then gravity was missing (quantum gravity still eludes us, of course) and many parameters helping to construct the model were arbitrary. After many developments in *quantum field theory* (QFT), and the employment of renormalization group theory, our understanding of the SM has changed radically. It is now construed as an *effective field theory* (EFT). An effective theory (ET) is that which captures what is relevant physically in, or at, a given domain, doing so effectively – it works, and it does so by ignoring all else (see Georgi 1995, 88). This results in a natural pluralism. Supporting this, Cao offers a vision, 'I would like to define a fundamental theory not as a theory from which we can derive all other theories, but rather, as a theory that cannot be derived from any other theory. In this sense QFT definitely is a fundamental theory. In the same sense the general theory of relativity is also a fundamental theory' (Cao 2003, 28). In physics sometimes the fundamental theory is characterized in terms of the tiniest length-scale or highest energy scale; by contrast, the fundamental theory is one that is coherent with all other accepted physical principles. The problem here being that GR fails on both counts, while QFT fails to meet the second criterion. Why? Because it does not incorporate the dynamic understanding of space-time that GR accepts (Cao 2003, 29). More crucially, physics does not reduce to physics (see van Brakel 2014, 33). We need physicists, after all. This is a version of the Quine–Putnam indispensability argument – the physicist is here indispensable, as are many levels of analysis, energy levels, and so on. Any such physicists leave their beds each morning for a reason, a good one, we wager, and head off to the lab, lecture hall, or to their desk, pursuing that which is deemed good, beautiful and true. As Aristotle tells us, 'For the good and the beautiful are the beginning both of the knowledge and of the movement of many things' (*Metaphysics*, 1013a 22–3).

Reductionism and Hierarchies

From the above we can begin to glean that *reductionism is false* – historically, philosophically, and scientifically. It is, moreover, a metaphysical claim. Indeed, we should wonder how reductionism is to *utter* data at all, given its own terms, for all components of said utterance would fall into the disarray of an insipid atomism. The sense of our concepts lapses into nominalism. Aquinas argues as much while expounding Aristotle (*Metaphysics*, VII.17.1673–4). Reductionism as a purveyor of ontological fundamentalism or microphysical fundamentalism with its requisite base element looks something like this:

1. The hierarchy thesis: The universe is stratified into levels.
2. The fundamentality thesis: There is a bottom level, which is fundamental.
3. The primacy thesis: Entities on the fundamental level are primarily real and the rest are at best derivative, if they are real at all (see Schaffer 2003, 498).

Attendant to the above are four interpretative frameworks for the idea of 'level': *mereological*, part to whole,[5] wherein the whole is composed by its parts; *supervenience*, which invokes asymmetrical relations of dependency, the higher being wholly indebted to the lower; *realization*, here, all functions are realized in lower level properties; lastly, *nomological*, this simply means there are *one-way* bridge laws between levels, in which the higher is reducible to the lower (Schaffer 2003, 498–517). Here we have our layer cake:

> The hierarchy of levels is a hierarchy of sets of entities corresponding to the universes of discourse for different branches of science. This hierarchy is arranged so that the branch of science dealing with level *i* is a 'potential micro-reducer' of the branch of science dealing with the next highest level *i* +1 in that the entities from the higher level can be decomposed into entities at the lower level. It is further stipulated that any whole that's exhaustively decomposable into parts belonging to level *i* also belongs to *i*; thus, the population at each level includes all entities at higher levels. The hierarchy of layers is therefore ontologically conservative in the sense that moving up in the ordering does not add any ingredients to the world: all entities are already contained in the bottom layer, the level described by the most basic theories in physics. (McGivern and Rueger 2010, 381)

The temptation of hierarchy provides a sort of artificial neatness. What it reveals, quite clearly, is philosophical prejudice. It does so because the order of discovery is the reverse of what it should be: we discover hierarchy before we look. Interestingly, when physicists speak about levels it's more a question of the stratification of reality into processes, scales, behaviours and so on, rather than that of hierarchy as such (see McGivern and Rueger 2010, 381). Nickles' most telling observation is that there are two forms of reduction (I would argue there are many more, such as cultural). Let us call this *reduction in two flavours:* that of physics and philosophy, which portray an annoying terminological orthogonality (see Berry 1994, 598). First, in physics a typically newer and more refined theory is said to 'reduce to' an older and coarser theory: a finer theory such as relativity does in a sense 'reduce to'

5. 'Mereology' was coined by Léniewski (1886–1939).

Newtonian physics under the 'conditions' that supported the Newtonian theory. Relativity is thus said to 'encompass' Newtonian theory. Philosophy, meanwhile, tends to have a higher, less general theory, which is older, 'reduce' to a lower, more general, and more recent theory. Against the direction assumed by philosophy, consider, for instance, that certain features of rainbows can be fully understood only through asymptotic methods: in effect, there are universal features that emerge in the asymptotic domain as the wave theory approaches the ray theory in the limit as the wavelength of light approaches zero. These features inhabit, so to speak, an asymptotic borderland between theories (see Batterman 2002, 9–22; Chibbaro, Rondoni and Vulpani 2014, 31–2). The phenomena inhabiting this borderline are not explainable in either purely wave-theoretic or ray-theoretic terms. A full explanation of what we observe in the rainbow cannot be given without reference to the asymptotic domain between wave and ray theories. The relevant phenomena are simply not reducible to either theory: to neither the more 'fundamental' wave theory nor the 'coarser' ray theory. They cannot be predicted from the properties of the more fundamental theory, even though they are in a sense asymptotically contained in that theory. This should give pause to much philosophical ambition of recent times.

You Can't Have Your Ingredients Without Your Cake – Macro Phenomena and Renormalization

Another challenge to hierarchical reduction comes in the form of the relationship between the macro and the micro level. Batterman's approach to the question of multiple realization (made famous by Jerry Fodor) is promising, insofar as he endeavours to answer the perennial conundrum of how heterogenous systems at the micro-scale are homogenous in terms of their behaviour at the macro level. This, quite correctly, is a major challenge to reductionism. He does by invoking the phenomenon (an emergent one, as we shall see) of renormalization (especially, renormalization groups – RGs) (see Wilson). To repeat, how are there stable robust behaviours at the macro when there is no micro base for such a phenomenon, and micro realizers seem to be largely ignored? An example of this would be how theories of continuum scale physics (e.g. continuum mechanics, thermodynamics, or hydrodynamics, etc.) do what they do, and do it so well without appeal to the micro (Batterman 2017, 6). Orthodox thermodynamics is phenomenological, insofar as it treats a system, such as a gas in a box, as a continuous blob of stuff, thus when it describes (and explains) the observable behaviour of various systems like gases, it remains agnostic, indeed aloof about the internal constitution of those systems. Conversely, kinetic theory (and statistical mechanics) explains behaviour of a gas in terms of fundamental principles, but any success rests on forfeiting the encounter of the very phenomenon to be explained.

In dealing with macro phenomena, especially exhibited behaviour, renormalization steps in. For example, as Jackiw notes, 'ultraviolet infinities appear to be intrinsic to quantum field theory, and no physical consideration can circumvent them; unlike the infrared [low energy] divergences, ultraviolet ones cannot be excused away. But they can be "renormalized". (Jackiw 1999, 149–50). By appealing to the terminology of physics rather than that of philosophy new insights are afforded. The main terminological shift (though with very similar meaning) is from multiple realization to that of 'universality'. Berry puts it this way, universality is 'the slightly pretentious way in which physicists denote the identical behaviour in different systems. The most familiar example of universality from physics involves thermodynamics near critical points' (Berry 1987, 185). Put simply, different systems that consist in wholly different micro constituents do in certain circumstances act as if they were the same physical system.[6] For example, vastly different liquids (e.g. neon (Ne) and methane (CH_4)) converge on the same behaviour under particular circumstances, rendering reductionism in a bit of a quandary. Another way to put this is that one can 'change the "essential molecular features" of, say, methane into those of neon, without affecting the upper-scale behaviour … . This reflects a kind of *stability under changes* of the very nature of the systems. The renormalization group makes the metaphor of "morphing" one system into another mathematically precise' (Batterman 2017, 8). By way of an averaging rule the interactions between molecules are reigned in because of its enormity – averaging out allows for this as it begins the process of decreasing freedom otherwise the freedom is so vast, indeed infinite, that it lies beyond calculation in any meaningful sense. These averages then act or are treated as something 'real' or, better, as new molecular components, which makes sense because of the self-similarity displayed by systems near the crucial point (crudely, they sort of look like something, they manifest *form*, so to speak) (Batterman 2017, 9). In a sense one coarse grains one's analysis (like when we half close our eyelids to see better), screening-off that which is no longer relevant (Batterman 2017, 9). Moreover, the underlying high-energy physics is multiply realized, as it were, to the point of near indifference. In other words, any macro description that such a procedure provides involves a strong compression of data, a strong selectivity (see Morrison 2014, 1145). As we know, this whole procedure is one of art: 'There are no recipes for how to reconstruct an RG for a given universality class.' This being the case the reductionist is once again in trouble. 'Reductionists can never concede that coming up with the right blocking procedure is an art.' Consequently, renormalization is a liberator of the macro. This emancipation involves the lifting of the macro to a new realm or order, as Thalos calls it, but without jettisoning crucial relations with other realms; it is a marriage of equals (Thalos 2013, 239).

6. An analogy is to be found in evolutionary biology, namely the phenomenon of convergence (or homoplasy). There, unconnected creatures 'solve' evolutionary problems in the same way, suggesting that the biosphere is constrained: here the creatures are significantly diverse in the physical makeup (genotype, phenotype, environment, etc.), yet they end up at the same party, so to speak. A good example is that of the camera eye, which is found in humans and in octopus also.

Priority of the Pie – Autonomous Ontological Domains

In examining the relationship between the macro and the micro level we need to pay attention to the ontological status given to each (or indeed to the whole). Schaffer uses QFT to offer an interesting critique of microphysical fundamentalism. He posits what might be termed the thesis of 'infinite descent'. The purpose of which is to argue that an analysis that seeks a base element could always go further, and history seems to chime with his contention. According to Schaffer, 'Infinite descent yields an egalitarian metaphysics which dignifies and empowers the whole of nature. Treat infinite descent as a working hypothesis, and since all entities turn out to be composite, supervenient, realizes, and governed, it emerges that these attributes cannot be barriers to full citizenship in the republic of being' (Schaffer 2003, 51). The point being that if the world is infinitely decomposable then if there is any halting or drawing the line at a certain level it is question begging. If we do select a level as a dependence base, then we transform all that which might be below it into something nonphysical, and surely the physicalist does not wish to have such phenomena in its ontology. Schaffer baulks at the usual presentation of monism as the thesis that there is just One because according to him we are reading this all wrong. It is not that there is just One, but rather that the One is *prior* to its parts (priority monism). Here Schaffer is following the lead of Proclus, consciously so (see Proclus 1979, 79).

Put another way, *emergence* is metaphysically possible, *submergence* is not. If it were possible then the intrinsic properties of the proper parts, and the fundamental relations between these parts, must fail to supervene on the intrinsic properties of the whole, in other words, they stand alone untouched. For Schaffer, this is impossible because 'an intrinsic property of the proper pars ipso facto correlates to and intrinsic property of the whole, namely, the property of having-a-part-with-such-and-such-intrinsic property, and relations between the parts also correlates with an intrinsic property of the whole, namely, the property of having-parts-thus-and-so-related. Fix the whole, and all of its parts are fixed' (Schaffer 2010, 56). The point being that unlike the pluralist who is vulnerable to emergence the monist can provide an inventory of the world (Ciauncia-Garrouty 2013, 568).

Schaffer also appeals to the *asymmetry of existence*, which simply means that there must be a basic whole, but there need not be basic or ultimate parts. Schaffer's thesis of infinite descent is empirically supported, hence quantum entanglement, and it is, in addition, an empirically open scenario (Ciaunica-Garrouty 2013, 568). Interestingly Schaffer, too, invokes renormalization in QFT wherein, and following Georgi, EFTs 'might form an infinite tower which goes down to arbitrary short distances in a kind of infinite regression … just a series of layers without end' (Georgi 1989, 456). Consequently, the world is approached as layered into quasi-autonomous domains (or realms, as Sarkar prefers) (Sarkar 1998, 193, fn. 22) and each domain has its own ontology and its own fundamental laws (see Cao 1997). Laughlin and Pines baptize this insulation from micro reductions 'protectorates' (see Laughlin and Pines 2000, 28–31). Within such protectorates, scientific understanding need not rely on ever-decreasing scales of investigation. The emergent phenomena gain as much ontological status as the elementals, so-called. For Laughlin and Pines something as seemingly simple as the existence of sound in a solid is emergent, which is to say, we do not appeal to microstructures: 'It is rather obvious that one does not need to prove the existence of sound in a solid, for it follows from the existence of elastic moduli at long length scales, which in turn follows from the spontaneous breaking of translational and rotational symmetry characteristic of the crystalline state. Conversely, one therefore learns little about the atomic structure of a crystalline solid by measuring its acoustics' (Laughlin and Pines 2000, 29). As Nelson points out,

> The modern theory of critical phenomena has interesting implications for our understanding of what constitutes 'fundamental' physics. For many important problems, a fundamental understanding of the physics involved does not necessarily lie in the science of the smallest available time or length scale. The extreme insensitivity of the hydrodynamics of fluids to the precise physics at high frequencies and short distances is highlighted when we remember that the Navier-Stokes equations were derived in the early nineteenth century, at a time when even the discrete atomistic nature of matter was in doubt. (Nelson 2002, 3)

Importantly, Bitbol makes the point that 'the "never ending tower" of autonomous domains in Quantum Field Theory indeed concerns domains of study, domains of concepts, but not domains of being' (Bitbol 2007, 302). In short, we must not reify (see below), and this stands for all approaches in *scientia*.

> If the message of quantum physics is taken seriously, the critique of reification concerns not only the high-level properties but also the low-level properties; not only the emerging properties, but also the properties of the so-called basic constituents of the world. The reductionists eventually lose the game, because their so-called 'reduction basis' is as firm as quicksand, and because it proves quite easy in this case to put the emergent behaviour on exactly the same footing as the so called 'elementary' entities and laws. (Bitbol 2007, 295)

Weighing the Scales

While we have here established something of a democracy of scale, Thalos goes yet further and argues that there is no true scale to which activity is confined. Of course this has enormous ramifications for reduction. But also, according to Thalos, it also offers a challenge to emergence, which she thinks concedes too much to reductionism, and thereby corrupts their own insights: it carries the shadow of that which it rejects. This is, as Thalos argues, reductionism in sheep's clothing (Thalos 2013, 42). The universe is scale free, therefore, without hierarchy, it being more of a case by case matter, as it were: a matter of context, but not contextualism. Most importantly, locality is denied: it is not a universal feature of the universe, which is to say the move to reduce to 'somewhere' is gibberish (entanglement would surely support this contention) (Thalos 2013, 56). Not only is the base level unnecessary, there cannot be any fundamental level. Gone is the very notion of a base element, a fundamental level, a hierarchy, and by implication, the division of the sciences into special and otherwise, for there is no 'master science' (Thalos 2013, 7). Anderson concurs, even though he accepts reductionism, which for him means the ability to reduce everything to simple fundamental laws, he rejects what seems to be asserted concomitantly, namely, the constructionist hypothesis, which simply asserts that we can reconstruct the universe from those laws, which is impossible. In this sense reductionism becomes domesticated (see Anderson 1972, 393–4). And domestication is a correct term, for as Anderson points out, the more reductionism succeeds the less is achieved (see below). Weinberg in his fight with low-energy physics over the funding of the superconducting super collider argued that 'particle physics is in some sense more fundamental than other areas of physics' (Weinberg 1987, 434).[7] Such an understanding reflects Weisskopf's distinction between extensive and intensive research (Weisskopf 1965, 24). Anderson's riposte is most revealing: 'The more the elementary particle physicists tell us about the nature of the fundamental laws, the less relevance they seem to have to the very real problems of the rest of science' (Anderson 1972, 393). Condensed matter physics has cut into the nomological hegemony of high-energy physics (Humphreys 2016, 6).

Eddington famously challenged any attempt to reduce to either macro or micro, by asking us to choose between two accounts of a table: the micro physical, or the common-sense macro description. Are the macro properties of the table such as rigidity and solidity reducible to the micro-properties, do they supervene? But even this question is inadequate. There is no common denominator that provides the necessary structure for such a question to be asked. It is only by first accepting, which is just presuming, the hegemony of micro-physicalism or generative atomistic physicalism that any dilemma gains a semblance of intelligibility (Humphreys 2016, 16). The macro, emergent properties are global in scope, and as such can only be approached from a global perspective, for once again the micro cannot understand about what you are speaking. It must be remembered that different energy levels quite literally display remarkably different physics. We witness this insofar as QFT, wherein EFT is the correct way of describing the relevant physics in particular limited energy domains, is a matter of context and approximation, and in so being it is more real. This Cao points out is 'a pluralism in theoretical ontology, an anti-foundationalism in epistemology and an antireductionism in methodology' (Cao and Schweber 1993, 69).

Outside mathematics one would be hard-pressed to find an example of true intertheoretical reduction (see Howard 2007, 145). The example of the reduction of macroscopic thermodynamics to classical statistical mechanics is a telling demonstration of the impossibility of reducing macro to micro, or vice versa

7. For the politicization of science see O'McGarity and Wenger (2010).

(e.g. the reduction of the ideal gas law PV = nRT to statistical Mechanics). It does not work. 'Foremost among the thermodynamic laws that must be derivable from statistical mechanical postulates is the second law, which asserts the exceptionless evolution of closed non-equilibrium systems from states of lower to states of higher entropy. Providing a statistical mechanical grounding of the second law was Boltzmann's paramount aim in the latter part of the nineteenth century.' Howard asks, did he succeed? No, because what Boltzmann derived was a statistical simulacrum of the second law of thermodynamics. All this simulacrum can tell us is that closed non-equilibrium systems are at best highly likely to evolve from states of lower to states of higher entropy (Howard 2007, 146). More importantly, this statistical understanding is not deduced from first principles, or at least only when such principles are conjoined with what Howard calls the ergodic hypothesis: 'Regardless of its initial state, an isolated system will eventually visit every one of its microstates compatible with relevant macroscopic constraints' (Howard 2007, 146). So the question asked is whether or not macroscopic thermodynamic phenomena are indeed *emergent* rather than *resultant* from mechanical calculation (incidentally, both terms were coined by Lewes in the very same passage) (see Lewes).[8] It seems the answer is yes, and this is important to the extent that it undermines reductionist prejudice that trades on the success of intertheoretic reduction, which fails. In the case of non-ideal systems in statistical thermodynamics, the equations of the state used to estimate the energy of interaction between molecules cannot be deduced from any fundamental theory. A crucial factor is that of equilibrium, which is the central notion of thermodynamics, yet it is a macro feature. Take temperature, this only makes sense for a system in equilibrium, but it does not exist at the micro. We are therefore losing our 'cool', quite literally (see Lombardi and Labarca 2005, 131).[9]

Howard surmizes that the confusion arises because the understanding of particles has been wrongheaded; we think in too atomistic a manner. 'What we, today, call particle physics is, the name notwithstanding, not really a theory of particles' (Howard 2007, 155). Interestingly for this chapter, Lévy-Leblond employs the metaphor of a rainbow: particles have 'the mode of existence of rainbows' (see Bitbol 2008). No wonder, as a particle, properly understood, is but a manifestation of a quantum field; it is excitation of fields that affords the cardinality of subsets of particles to which they are in a one-to-one correspondence, not to mention permutation invariance wherein one particle can be replaced without cost to the

8. There is little doubt he was under the influence of Mill.

9. Howard's favourite example of the failure of reduction, and more precisely the scuppering of supervenience, is that of quantum mechanical entanglement, touched upon already, which is irreducibly holistic (it should be noted that we can understand such holism even in the absence of entanglement) (see Seevinck). Schrödinger who introduced the notion of entanglement called it 'not *one* but rather *the* characteristic trait of quantum mechanics' (Schrödinger 1935b, 555). On entanglement, see Schrödinger 1935a, 1936.

system (this being somewhat analogous to molecular turnover for organisms, when all our molecules are changed over time but we remain 'Susan' (see Chakravartty 2017, 139). In short, particles are themselves configurations, or patterns. In terms of reduction, condensed matter physics certainly enjoys explanatory autonomy because it can't be reduced, but again, not because of a failure of supervenience (if there is such a chimera).

It should be noted that a plague is visiting two houses, that of the reductionist and the emergentist:

> Deconstructing the formal concepts of substance and of property in Quantum Mechanics is precisely as challenging for the reductionist as it is for the supporter of 'true' emergence of high level intrinsic properties. The physical process may have no substantial roof of emergent properties, but it has no substantial ground of elementary properties either, according to the most straightforward reading of Quantum Mechanics. (Bitbol 2007, 302)

Yet a danger lurks here, one that would allow the return of the idea of a 'base', one Bitbol is at pains to point out, 'It is wrong to assert that Quantum Mechanics displays "ontological" emergence. What emerges is only a new mode of possible cognitive relation between the microscopic environment and the available range of experimental devices' (Bitbol 2007, 301). Appeal to Quantum Mechanics, is therefore, a matter of *epoché*, which is to say, it is to aid us in suspending our natural attitude (*die natürliche Einstellung*) to employ Husserl's phrase, but in so being must not itself assume the vacant place (Legion would then would be the new resident) (see Bitbol 2002, 202).

Another interesting example of an autonomous macro feature, one insensitive to micro constituents, is that of superconductivity. The point here is that superconductivity has all the micro constituents any reductionist would desire, as mentioned already, yet its defining features (infinite conductivity, flux quantization, the Meissner effect, for example), *transcend* any such base (see Teller 1992, 106). Pines and Laughlin point to this transcendence in terms of higher organizing principles, symmetry breaking especially. An example of such a principle is that of continuous symmetry breaking, that after all allows us 'to render exact the Josephson quantum, and localization, which is responsible for the quantum Hall effect' (Morrison 2012, 149).[10] Now, such transcendence means there is a strong sense of immunity to the 'small', that being the case they are what is referred to as 'model independent', that is, not causally linked to a microphysical base, as such things are a moveable feast, as it were (once again replacing fermions with bosons) (Morrison 2015, 106). When superconductivity is involved bosons crowd together, indeed they pile together to the point that they act as if they

10. Localization is the absence of diffusion in terms of waves that caused by a high concentration of defects or disorder in crystal or solids, which in terms of electric properties, and an appropriate solid, can turn conductors into insulators.

were one, and therefore as if there was no electrical resistance at all. It should be noted that due to what is known as Cooper pairing two electrons (fermions) act, or better become a single boson (this pairing is the result of being submerged in a sea of opposite-charged particles). Consequently, fermions act as a boson, and bosons then can act themselves as a single entity. Characteristics to be found in a boson (even though composed of fermions) have nothing in common with their constituents, indeed they stand in contradiction. Again, what is crucial in understanding a system is not its elements, change as they do, continually, but the bonds of that system, which are ineliminable. As Morrison says, 'symmetry breaking (here the breakdown of elector magnetic gauge invariance) provides the explanation of emergent phenomena but the specific microphysical details of how the symmetry is broken are not part of the account' (Morrison 2015, 106; see Morrison 2006, 881). 'You cannot make a magnet by putting dipoles together "one at a time". Cobbling is simply not available. You have to act on them all at once. That's what resheathing is: acting at a higher scale so as to contain a new state upon things at lower levels' (Thalos 2013, 97). This is analogous to Haaken's work on lasers, in terms of his notion of the 'enslaving principle'; indeed, it is analogous to biological systems *in general*.

Thalos gives the example of a painting, which is approached atomistically will permit only a version of a Pointillist painting, all that is macro is really an aggregation of the micro, but this is wrongheaded. First, the painting requires a suite of coordinated, mutual effort, from the materials to the painter. Second, any notion of the pointillist perspective being the real (here the micro) is wrong, for even if we were to allow this incoherent notion, any point, as it were, would become a painting of its own, and so on, downward, but crucially, up also. Kim argues that 'to cause any property (except those at the very bottom level) to be instantiated, you must cause the basal conditions from which it arises (either as emergent or as resultant)' (Kim 1999, 24). But surely, as Thalos asks, is this not simply sheer prejudice against the macro? Yes, is the very easy answer. Why can we not simply speak about bringing about the macro directly? (Thalos 2013, 99) After all, as Butterfield asks, 'Whoever said that ontology concerns only "supervenience basis", i.e., the putative set or level of facts that determine (subvene) all other facts? That is: there is plenty of scope for ontological discussion of supervening ("higher level") facts and theories.' Well, we can, indeed we do, no matter the overlay of micro language, for the micro is so underdetermined that it only splutters into talk when summoned by the macro: here it is the puppet, and never the master, for it's recruited, gang pressed even, and made to do or be something by way of participation. Yet we should point out that in some sense we can say that the macro is part of the micro, the converse also (see McGivern and Rueger 2010). Indeed, McGivern talks of a *mixture* of the micro and macro scales (McGivern and Rueger 2010, 389, fn. 12). 'We take the mixed solution seriously as a description of the behaviour of the system that is indeed composed of ingredients from both scales' (McGivern and Rueger 2010, 393). In other words, it is what it is only by what it relates to, and therefore is told what it is, it does not tell us; sure, what it can afford is a given potential, but its content and extent are not susceptible to any form of analytical closure. We can intervene analytically, which is to intervene on the 'parts'; with synthesis, by contrast, we intervene at the global level, and there we deal with the whole. These two must work in concert. For the former involves upward causation, the latter downward, but they are not in competition (see Bitbol 2012, 244). This point can be reinforced when we consider what it is that reductionism seeks to hide from us. Namely, the null possibility, in other words, there could be much less order, to the point of there being none. The reason this is hidden from us is because its possibility reveals, as we have suggested, that even the most basic element supposed by physicalism is a result of order, it is not just there – language such as base, with the inflection of minute size, so small as to not warrant explanation is mere assertion. But no, the very real possibility of nihilism scuppers the innocence or unproblematic ordinariness of the micro.[11]

Cooking with Chemistry

By moving our attention to chemistry, we see a possible escape from the shackles of both reduction and emergence. As we know already, a crucial phenomenon is that of symmetry breaking, which is essential as it induces or allows for the advent of structure and hierarchical levels, importantly, though, all such levels, and indeed subsystems cannot be subsumed by first principles; they cannot because they lack an ordering principle, which is to say, the hierarchy of theories has the structure of a non-Boolean lattice. As for symmetry breaking, think of a vertical pole on a flat plane, before any fall the pole has 360-degree symmetry, but if it does fall then this symmetry is broken and a new macroscopic feature emerges. Anderson applies this to many types of chemical molecules, for example glucose, which is a six-carbon sugar molecule that is synthesized in our cells. Now, such molecules are characterized by a handedness, what is called chirality (*cheir* means hand in Greek), and this gives rise to enantiomers or enantiomorphs. The simple point of Anderson's analysis is to bring attention to the fact that glucose involves a break in left-right symmetry, it does because glucose molecules are only ever right-handed, but in so being no physical laws are violated, yet these same laws cannot tell us why organisms enzymatically construct only right-handed sugars (or similarly why the amino acids that make up proteins are left-handed). Symmetry and structure are inversely correlated, for instance a snowflake has much greater structure, yet the water in a snowflake once dispersed throughout a room has much greater symmetry (Ward 2010, 261). This is a phenomenon that rides above and between different theoretical frameworks, it does because it functions as a structural constraint, and this is applicable to both low- and high-energy physical systems.

Morrison gives the example of the electroweak theory which postulates symmetry breaking by way of the Higgs mechanism that is said to explain bosonic

11. On the possibility of the type of nihilism meant here, see Coggins (2010) or Lowe (2002).

masses; in addition, superconductivity involves symmetry breaking, again via Cooper pairing. These facts of life cannot be deduced from physical laws; rather, they are emergent properties, being so in the strongest possible sense, but not in a bid to outrun reduction, there is no need, for as we said above they are not in opposition. Morrison characterizes the situation thus:

> The relation between ontological and epistemic independence is especially important since the latter is a necessary but not sufficient condition of emergence; the fact that we need not appeal to micro phenomena to explain macro processes is a common feature of physical explanation across many systems and levels. Instead, what is truly significant about emergent phenomena is that we supposedly cannot appeal to microstructures in explain or predicting these phenomena even though they are constituted by them. (Morrison 2015, 92)

Morrison's contributions to this area of debate are excellent, but I am tempted to disagree with the idea that the pervasiveness of epistemic independence in terms of the micro in relation to the macro means that the appellation emergence is withheld. For Morrison it must be that we cannot appeal to microstructure *tout court* that bestows the title. Crowther argues that emergence is better thought of in terms of novelty and autonomy – an autonomy that frees its manifestation from inclusion in a comparison, as such. Such novelty and autonomy are discernible by way of underdetermination and renormalization, and arises because of, for example, symmetry breaking.

For Crowther, avoiding conflation allows us to decouple reduction and emergence and this frees emergence up, thereby enabling it to be picked out on its own terms, which is to say it is not necessarily articulated in terms of a rejection or scuppering of reduction (see Butterfield 2011). That being the case its pervasiveness can be embraced. Such an embrace is made possible because we are not concentrating on the relation between levels, but rather on the ET itself, one that presents novelty and autonomy right before our eyes that need not stray elsewhere. As Crowther says, 'The positive conception of emergence as being simply novelty and autonomy of the low-energy physics compared to the high-energy physics means we can consider individual cases of emergence' (Crowther 2015, 439). As a result, we can consider emergence even before universality (it being only potentiality). Imagine having only one example of an emergent phenomenon, such as a superconductor, composed of a particular metal, well, Crowther argues, we would not be able to speak of it as emergent. Instead if we simply look at the phenomenon and what it entails the idea of reduction does not appear, nor even fail to appear, so speak. According to Crowther the gauge symmetry is all that matters here, and not the micro, but we are it seems forced to label such a phenomenon as being merely resultant. This is most interesting. Two quick points. We must ask is Crowther's point not retrospective, which is to say, she must be carrying the idea of reduction within the analysis, however unconsciously, otherwise why make the point: why pick out superconductivity or notice it. Crowther can escape this dilemma and reach her analytical observation if we abandon emergence and reduction as stable terms. After all, the simplicity of reduction invokes a complication all of its own, perplexity is even more forthcoming, or at least just as much. Of course, we might be worried that this leads to vacuity. But no, not if we have recourse to effectiveness as our approach, indeed tool of analysis. Both reduction and emergence tell us about the sheer richness of our common cosmos.

Carbon offers an intriguing insight into just how complicated yet ordered the reality we try to explain is. Carbon is tetravalent, which simply means that it can bind to four chemical groups. For example, in chloroform it is bound to one hydrogen atom and three chlorine atoms ($CHCl_3$), while in methane, carbon binds to four hydrogen atoms (CH_4). When it is bound to four different groups, as with natural α-amino acids, two different forms are made manifest, which are chiral: they are mirror images of each other but are not superimposable (see above). Yet only the L-form (left-handed) of natural α-amino acids is present in nature (exceptions are almost negligible). A compound bearing the same molecular formula, yet a different structure is called an isomer. And those with different spatial order are termed stereoisomers, and the two chiral mirror images are enantiomers (or optical isomers). When natural α-amino acids are synthesized a 50/50 mixture of the enantiomers is produced. But as said nature only employs the L-form, and that which shares the chirality it is referred to as homochirality (e.g. all proteins, natural sugars, and so on). If nature abhors a vacuum, she loves asymmetry. The ubiquity of L-form natural α-amino acids reduces the combination from trillions to a single protein having only one optical isomer, this allows the production of structure and order, otherwise nature would be something of a Buridan's ass, just with a near infinity of plates from which to choose, and nothing would follow from that. The asymmetry at the molecular level allows the manifestation of symmetry at the macro, thus there are things to be known in reality, or indeed there is an intelligible reality at all: A cosmos. But the story does not stop there, because although the macroscopic is symmetrical it too involves symmetry breaking, and the resultant asymmetry accommodates innovation. Asymmetry can be found throughout nature, for example the seemingly ubiquity of the helix, from plants to DNA, a wonderful explanation of this is the Fibonacci sequence (and its related golden sequence), which reveals how the self-similarity involved in phyllotaxis makes sense (a beautiful, conspicuous example of this is the shell of the Nautilus, a snail mollusc).

Domains

Echoing the point Cao made above, once again instead of levels we see that it makes sense to think in terms of enclaves of order, or domains, thus escaping any proprietary manner of speaking (Thalos 2013, 22; Humphreys 2016; Agazzi 2014). We do so because domains are more dynamic, overlapping, indeed mutually reinforcing, or as Humphreys would have it, neutral (metaphysically speaking, that is, not in bed with physicalism): Agazzi calls them regional ontologies (Humphreys

2016, 39, 121). Moreover, talk of domains allows us to speak of elements from one domain being reduced to another one, or elements of one domain emerging from another domain, but when one does so there is no implication of hierarchical ordering (Humphreys 2016, 122). If we cow-tow to physics as a master science we must face the simple dilemma: 'Physics cannot tell us why Biology exists' (Thalos 2013, 26). As we read above, Thalos advocates a scale-free model, which insists that difference in scale does not mean a difference in level, by now asking what a level would be, as we can't seem to find one. It is not that we don't rest on the shoulders of giants, we do, but at the same time those who we rest upon, we hold up, for there is no 'floor' (or base) beneath the feet of those giants. Indeed, the use of the word 'beneath' should be wisely set aside. According to Thalos, reductionism fails because supervenience is not fit for purpose, and emergentists half agree (as we know). Put differently, the ordinary is extraordinary at the same time as the extraordinary is ordinary. Once again, B traits supervene on A traits, such is the case that there cannot be a change in B traits without a change in A traits and from this comes the point (made most strongly by Kim), that surely, and applying Ockham's razor, why bother with the B traits at all, in terms of deeming them real, rather than epiphenomenal, and therefore lacking independent causal efficacy: mere shadows cast by the real stone. How do we even pick out B traits, to then reduce them, and how does any such process of dismissal get going on reductionist terms, for surely it is laced with higher/different order traction. Supervenience would mean that when A-characteristics are held fixed, B-characters will be fixed as well. But here's the rub: why can't we look at it from the other way around? That is, when B-characteristics are fixed so too are A-characteristics, and any notion of priority can only be smuggled in extraneously, that is, by way of presumption, not argument. This is suggestive, for once again we can begin to realize that reduction is not in opposition to emergence, nor the converse, yet both have borrowed logics, otherwise they are but placeholders. Downward and upward causation are not to be thought of as either real or illusory, rather, for Bitbol, they should be thought of as two modes of intervention that are indexed to their appropriate level of intervention.[12] According to Bitbol we should replace foundational, substantialist dualism with a functional duality of domains. (To some degree he shares this understanding with Humphreys and arguably Thalos.) Again, the problem with both reductionism and emergentism is that both presume a substantial dualism between base parts and relational wholes.

> The miracle is the only thing that happens, but to you it will not be apparent,
> Until all events have been studied and nothing happens that you cannot explain
>
> (W. H. Auden, *For the Time Being, Recitative*)

12. That being the case, they are not substantialist theses as they contribute to the very definition of their terms, therefore they are relational concepts (Bitbol 2012, 234).

It's All in the Mixt: Fusion Cooking

Chemistry operates with a completely different ontology than physics, in so doing the purported gap between the sciences and the humanities is bridged; not that there is a gap to be closed. Rather, different modes of engagement need to be recognized and each given their appropriate ontological weight. That being the case, chemistry serves as a major force to collapse the logic of reductionism and as a vehicle for the return of *scientia* and the abandonment of 'science' as a stand-alone term. (We should recall that the word 'scientist' was only coined as a term of art in 1833 by William Whewell, and was resisted until around the First World War.) Chemistry proves to be a hinge between the humanities, so-called, and the natural sciences. Kant famously said that chemistry was an *uneigentliche Wissenschaft* (though the context is often ignored), but after his so-called *Übergang* (or transition) he went so far as to say that 'philosophy always belongs to chemistry' (van Brakel 2013, 69–94). Chemistry is founded on a form of art – Man as *Homo faber*, indeed *Homo creator and Homo prospectus:* 'Everything in sight has the chemistry's art written into it' (Baird, Scerri and McIntyre 2006, 4). This forces us to rethink our scientific ontology *as a whole:* what nature entails will become more expansive, challenging the division between *techne* and *physis* – after all, Aristotle said that *physis* depended on art.

What, then, is this ontology? For a start, the dilemma of realism versus positivism is irrelevant; chemistry in a sense accepts neither. It is operationally realist, certainly, but the world of chemistry is more open, more conscious of the constitutive interventions of questions, experiments, and so on (see Bensaude-Vincent 2008, 52). But this does not mean it is less of a science, rather it is in this regard, more of a science. In addition, chemistry extends our understanding of reality, insofar as its ontology extends to incorporate the fabricated. A crucial point is that relation and plurality are the 'basis' of chemistry, so too processes, not some pretend kernel. This is important for several reasons. For the sake of space let us browse only a couple of these.

As we know, the microphysical, the apparent base, the one over which philosophy fawns does not even know *what it is or can do* without the macrophysical – it is blind and dumb, so to speak. Some examples: carbon, hydrogen and oxygen are not 'sweet', but $C_{12}H_{22}O_{11}$ (i.e. sucrose) is. As something of an addendum, only when such chemicals are taken up and metabolized does sucrose come into existence. Similarly, acidity is not reducible to a micro base, for it is a behaviour, one that is multiply realized. This idea that something is defined not by what it is, as it were, but what it does, or indeed is done to it goes back to Alan Turing and Alfred North Whitehead. One might think that alcohols are 'reducible' (they being a molecular group that bear a hydroxyl bond), that is true, but what different alcohols afford are radically different despite the same molecular base (isomers): take dimethyl ether and ethyl alcohol, both C_2H_6O, described by the same Hamiltonians (the measurement of the total energy in a system, in whichever form), yet their structures are represented as $(CH_3)_2O$ and C_2H_5OH – one gets you drunk while the other does not; once again, take C_3H_8O, this gives rise to three isomers, namely, methoxyethane, propanol and rubbing alcohol. So from where does the difference come? (Bensaude-Vincent 2008, 214; see Hendry 2017, 149) It seems it must be generated because of the relevant molecular structures (see below). Unsurprisingly, quantum mechanics has a problem with isomers (a problem if one is employing it for reductive purposes) as the same wave function is applied despite the different molecular structures. When any base is used, it is *used up* in the formation of the whole. Here we are back with Plato and Aristotle's 'mixt'. As Nordham points out, 'the problem of mixt has never been resolved or displaced' (Nordham 2013, 731). Take Hamiltonian operators, which are not just resultants but also configurational, the former being but a special case: reduction requires all Hamiltonians to be merely resultant. As Aristotle says, 'To the eye of the Lynceus nothing would be combined' (Aristotle, *De generatione*, I.10, 328a13f.). Consequently, the 'mixt' as he called it would be a fiction, or only apparent. If there was to be a true *mixt* then a new stuff had to emerge, one in which constituents were no longer there in actuality, or (to put it in cruder terms), but only in potentiality (see Aristotle, *De generatione*, I.10, 327b23ff.). Millenia later, Pierre Duhem captures the either/or condition of a *mixt* well: 'What in general, then, is a mixt? Some bodies, the one different from the other, are brought into contact. Gradually they disappear, they cease to exist, and in their place a new body is formed, distinguished by its properties from each other of the elements, which produced it by their disappearance. In this mixt, the elements no longer have any actual existence. They exist only in potentiality, because on destruction the mixt can regenerate them' (Duhem 2002, 5–6). The biologist Young brings to your attention a telling situation. He argues that the essence of a living thing is that it consists of atoms caught up into a living system and made part of that whole. In so being it disappears – a *mixt*, in our terms (see Young 1971, 86–7). Think of when a sperm joins an ovum, they both cease to be, and a new entity is produced. Or take Aquinas' notion, following Aristotle, that there are three types of soul: vegetative, animal and rational. These three combine, and therefore mix, in so doing a person is created, there now being only one soul, which is the substantial form of the body. This is analogous to Humphrey's idea of fusion, which is 'meant to show how supervenient relations fail to apply when fusion occurs, that role is generalizable to any similar dependency relations' (Humphreys 2016, 72). What does he mean by fusion? Quite simply, and again echoing Plato and Aristotle's notion of *mixt*, (micro) parts when combined, here fused, no longer exist, so we cannot speak about a base at all – the micro disappears.

Consolidating the above insights, we should understand that a molecule plus its environment can be thought of as a supersystem, and such a system appears to have the power to break the symmetry of its subsystems thereby generating structure, as all symmetry breaking appears to (see above), yet any such power does not appear to arise from any of the supersystem's subsystems. Surely, Hendry asks, is this not downward causation? The Coulomb Schrödinger equations describe mere assemblages of electrons and nuclei rather than molecules, which are structured entities. (This is illustrated, as we know, by the fact that isomers, which are distinct molecules sharing the same molecular formula, share the same Coulomb Schrödinger equation.) (Hendry 2010b, 186). 'Molecular structures cannot be recovered from the Coulomb Schrödinger equations, but not because of any mathematical intractability. The problem is that they are not there in the first place' (Hendry 2010a, 213). According to Vemulapalli the applications of quantum theory to chemical bonding involve calculations of quantities that have neither representation nor status in the original theory. Hence, 'many extra-quantum assumptions must be made to adapt the basic theory to the form that is useful in chemistry' (Vemulapalli 2006, 196). These assumptions surely confirm Wooley's worry that molecular structure as a 'universal attribute in molecular science is … not securely founded in quantum theory'. Consequently, it must be put in by hand (Wooley 1978, 1007; Wooley 1988, 56). 'The same event can have a chemical or physical description … but no privileged description exists' (van Brakel 2000, 171).

This lack of privilege, the God's-eye view, becomes evident, at least it does in relation to chemistry, when we realize that if quantum mechanics turned out to be wrong, molecular shape, chirality, and so on would persist, quite happily. The relation, therefore, between physics and chemistry is not asymmetrical, but rather symmetrical (see van Brakel 2000, 177). To use acid as an example: Acidity as a function seems to make sense in terms of affordance.[13] An acid is a substance that produces carbon dioxide when it comes into contact with calcium carbonate or sodium; it also turns phenolphthalein, which is red, colourless. So, an acid is realized by being acetic acid, or sulphuric acid, the property of being hydrochloric acid, and so on, but where, we might ask, is the unifying principle, for all such realizers are disparate. However, the Lewes concept of acid seems to challenge the above.[14] According to this account, an acid is an electron-pair acceptor. Consequently, sulphuric acid, hydrochloric acid, and so on qualify as an acid because they bear this property of accepting an electron pair. This common feature provides unification for a range of functionally characterized substances by way of this physical property. That being the case we cannot really speak of emergence; indeed, it is more accurate to speak of reduction: chemical property (being an acid) = physical property (electron-pair acceptance). Moreover, can we not now question the functional characterization of being an acid? I'm not sure. I wonder if the same functionalization does not simply reappear at a different level, or more accurately in a different way. That which qualifies as being acidic taking the physical property as decisive seems odd, insofar as they are very different, yet they are realizing the same behaviour. Also, sulphuric acid is characterized in terms of electron-pair acceptance, does this mean that all such acceptance leads to the same result?

> The symmetry problem impacts on ontological reduction via its commitment to the completeness of physics in two ways. The first is direct – if the acidic behaviour of the hydrogen chloride molecule is conferred by its asymmetry, and the asymmetry is not conferred by the molecule's physical basis according to physical laws, then surely there is a prima facie argument that ontological reduction fails. (Hendry 2010b, 187)

13. A neologism coined by J. J. Gibson in 1979.
14. There are also accounts of acid such as that offered by Arrhenius and Bronsted-Lowry conceptions.

Prevalent in much thinking on mereology is that of Armstrong's idea of an *ontological free lunch*, in short, 'mereological wholes are identical with all their parts, taken together Symmetrical supervenience yields identity' (Armstrong 1997, 12). (He apparently does not understand the fusion involved in every *mixt*.) This is not true for chemistry; indeed, it is not true for much. For example, it does not apply to most chemical combinations. What is implicit in Armstrong's thinking is the idea that once you have identified the 'individuals' then when they are thought to be in a system they will remain the same 'individuals', but this is not even close to reality. Take the example of hydrocarbons. Earley makes the simple point that even when analysing relatively small hydrocarbons, by way of NMR spectroscopy, what is revealed and is revealing is that there are many types of hydrogen atoms to be found and in addition various types of carbon atoms all of which exhibit different properties (see Earley 2006, 213). In short, combination is transformation. But we are bewitched, once again, by a false picture: 'being identical molecule for molecule = identity'. Van Brakel asks,

> Does any such identity include the velocities and relative position of the molecule? If it does, then it undermines the idea of macroscopic objects being identical 'molecule for molecule' because the velocities and relative positions of the molecules are constantly changing. If it does not, then, say, temperature would be excluded as a relevant macroscopic parameter for two objects being (in)discernible. At the macroscopic level everything is statistical and changing – hence no two things are ever the same'. (van Brakel 2000, 79)

Van Brakel admits that such differences are averaged out, approximately at the macro level, sure, but that is not the level so desired by the microphysical fundamentalist.

To break with this bewitchment, as mentioned, it is crucial that we alter our conceptual image of essences, especially of the notion of microphysical essence, for any underlying essence, so-called, varies with context, indeed it is variable as nominal essences. Returning to the question of water once again it is important, as von Brakel makes clear, that we realize there are H_3O_+ and OH^- ions in liquid water. There are H_4O_2- molecules as well as other H_2O polymers in water vapour. Moreover, temperature and other contextual variables dictate how much ionization or dimerization and polymerization there is. Water can be thought of then, pragmatically as H_2O, in terms of necessity, but never in terms of sufficiency (Van Brakel 2000, 80). In short, water is not simply H_2O (see Chang 2014). Once again, that is because there is no one microphysical structure or essence, or at least essence as it is normally understood; context and function have an enormous part to play in an understanding of such materials, or 'stuff'. Luisi provides another telling example, that of the aromaticity of a benzene molecule. The point being here that any such property is not, of course, there in the atoms of that molecule. But more importantly, 'when a benzene molecule is created, the orbitals of the carbon atoms and those of the hydrogen are changed; the molecule as a whole affects the properties' (Luisi 2002, 183–200). The molecule constrains its parts, certainly in this case, in terms of motion. Therefore, there is emergence, and our lunches start to look anything but free.

As the story we are often told, goes, 'A great deal of classical chemistry has been reduced to atomic physics', that is, the contention of Oppenheim and Kemeny (1956, 7). Hans Primas is having none of it. He responds by pointing out how quickly reduction is scuppered by quantum mechanics: 'According to our present understanding of the first principles of quantum mechanics, atomism as well as reductionist-mechanistic philosophies have no longer any scientific basis … . Modern quantum mechanics compellingly demands a *multitude of context-dependant* descriptions. Atomism is dead, the material world is certainly not constituted out of independently existing elementary systems' (Primas 1991, 165).

Tellingly, mechanics is in fact very much against supervenience. As Thalos points out, 'According to analytical mechanics, macroscopic structures – whether imposed externally or simply known to hold – are treated as limitations on the total number of dynamically micro-possibilities, from "above" as it were.' Indeed, mechanics allows microquantities to serve as manifestations of degrees of freedom. Such mechanics refrains from introducing quantities, such as forces, that mediate between the actual and the possible, hence it leaves gaps, doing so in the absence of strictures as to how they should be filled (Thalos 2013, 85). Crucially, mechanics takes the independence of boundary conditions as fundamental, and therefore as priority, hence not derivative. A major consequence of such analysis is summed well by Lanczos, 'The analytical approach to the problem of motion is quite different [from the Newtonian approach]. The particle is no longer an isolated unit but part of a "system". A mechanical system signifies an assembly of particles which interact with each other. The single particle has no significance; it is the system as a whole which counts' (Lanczos 1949, 4).

The art, the alchemy that chemistry both is and reveals (biology also), can be better noticed when we realize that reality is so dynamic, as mentioned already.[15] Returning to the question of microstructures helps. Matter is always restless it is never

15. Interestingly, New Mechanists such as Bechtel and Craver do not embrace reductionism, insofar as any notion of deductive-nomological reduction is rejected, and there is a constant appeal to multi-level explanations arguing that mechanisms occur in nested hierarchies (see Machamer, Darden and Craver 2000). Such pluralism is evident in chemistry, as we shall see, but in biology also. Biology now employs many different approaches, such as evolutionary developmental biology, systems biology, synthetic biology, epigenetics (whereby traits are inherited from the environment and passed on not via the genotype, crudely put) and so on. Or again, biology not only deals with the survival of the fittest (a biology of becoming), but the arrival of the fittest also (a biology of being). There is, so to speak, both a theatre (structure, or being) and play (phylogeny and survival). The reason for this being is that if there is to be biology at all, and not merely the flux of phylogeny, which is itself nonsensical, then such metaphysically rich approaches are required. Under the cosh of reductionism biology loses its domain, including the organism. We now realize that quite the opposite is happening.

quiescent. Indeed, as quantum mechanics has demonstrated the dynamic nature of matter, just as relativity theory shows that matter cannot be separated from its activity. (In this sense Francisco Suarez was incorrect for not even God could create pure matter, that is, a matter wholly devoid of form, empty matter. Aquinas insisted God could not, unlike Suarez, something for which Aquinas was condemned for asserting in 1277, in Paris.) There is stability in matter, but it is more like what Ludwig von Bertalanffy coined *Fließgleichgewicht* ('flux equilibrium'). The neglect of matter's dynamism is of course apparent in microphysical fundamentalism.

Size matters: It should be brought to the attention of our imagination that 'if we decrease the size of particles of the same chemical substance down to the nanometer scale, their stuff properties begin to vary at a certain size. Moreover, in that size range the properties also vary with the shape of the particles. It appears at the nanometer scale *form* philosophy takes over' (Schummer 2008, 16; emphasis mine). Put simply, the smaller the particle 'the more atoms are on its surface compared to the number of bulk atoms; and surface atoms behave differently from bulk atoms and differ in their behaviours depending on surface curvature' (Schummer 2008, 16).[16] The point being that molecular structure is not enough to classify in a safe and useful way. For example, toxicity is a disposition, of course, but one that only occurs by way of interaction. Take Gold: at bulk level it is non-toxic, yet gold nanoparticles are cytotoxic – it all depends on *size*. Thalidomide provides another example of such variance in terms of affect. Thalidomide usually consists in two optical isomers, and these are mirror image structures, which offer a very subtle difference. The problem being is that one of these is an effective treatment for morning sickness while the other causes all the dreadful birth defects we have come to associate with its name. So, we are back with Plato's *pharmakon*, wherein we cannot decide whether something is poisonous or beneficial. Once again, the microphysical is 'dumb and blind', they know not what they do. As Paracelsus put it, generalizing this ambiguity to all substances: *Alle Dinge sind Gift, und nichts ist ohne Gift; allein die Dosis macht, daß ein Ding kein Gift ist* ('All things are poison, and nothing is without poison; only the dose permits something not to be poisonous'). We are in the *mixt*; we are a *mixt*: a composite of form and matter, as Aquinas would say, or in tripartite terms: body, soul and spirit being so as one person.[17] Consequently, in terms of *mixt*, there can be no body either *simpliciter*. Indeed, 'the mystery of body is no less deep than that of mind. Therefore, there

16. This is the sort of conundrum faced by *REACH* (Registration, Evaluation and Authorization of Chemicals), that which is used by the European Community.

17. Interestingly, Philo of Alexandria, Flavius Josephus and St Paul all writing at the same time argued for just such a tripartite anthropology, a mixt. Of course, this was taken up by most of the church fathers such as St Irenaeus: 'For that flesh which has been moulded is not a perfect man in itself, but the body of a man, and a part man. Neither is the soul itself, considered apart by itself, the man; but it is the soul of a man, and a part of a man. Neither is the spirit of a man, for it is called the spirit, and not a man; but the commingling and union of all these constitutes the perfect man' (*Against Heresies*, VI, I).

is no provision in physical science for how to count bodies, even once we have produced an inventory of quantities or the features making an appearance within a certain spacetime' (Thalos 2013, 81). Aristotle would have agreed, doing so because he realized that we are a mixt: 'There is no part of an animal that is purely material or purely immaterial' (Aristotle, Part. An. 1.3643A, 24–6). Thus Plato warned, 'We ought not to seek the good in the unmixed life but in the mixed one' (Plato, *Philebus*, 61b).

Conclusion: A Bun in the Oven

For Plato, Aristotle and Aquinas following them, it is true to say that *omnis scientia bona est* ('all knowledge is good'). This idea must, however, be set over and against the vice of *curiositas*. Consequently, knowledge must be accompanied by the virtue of *studiositas*.[18] Clement of Rome wrote a letter to the Corinthians, it being the oldest datable document of Christianity, and in it we find the following: 'The head is nothing without the feet, and so the feet are nothing without the head … but all conspire (*panta sympnei*) and are united in their subordination to the task of preserving the whole body.'[19] All breathe together (Greek *sympnei*, Latin *conspirant*). The originally medical language is extended beyond biology to anthropology, but still further, for the *sympnoia* of the parts is meant, then, to communicate the universe entire (the Cosmos, which derives from the Greek 'κόσμος' for order) as a *sympnoia pantōn*, one underwritten by a shared *skopos*, or *telos*, which is the *eros* of all knowledge, *scientia*. Crucially, according to Aquinas, God is 'the final end of the whole universe' (SCG, I,I). As a philosopher of science puts it, if all knowledge is good, it is because it involves a form of faith summoned by desire. 'If the realization of the real involves participation in the real, the separation of mind and world as separate spheres is no longer possible and with that, there is also no separation between the superficiality of mere appearances and the depth of explanatory structures behind the appearances' (Needham 2012, 737). It should be remembered that when in the Hebrew Bible we are told that 'Adam knew his wife' (*Genesis* 4.1), the term 'knowing' is the same for sexual intercourse and the cognitive act. This Hebrew word for knowing is *jadah*. As Aristotle says, 'For the mind somehow is potentially what it thinks (*ta noēta*)' (*De anima*, III 4, 429B30-31). Again, 'Knowledge thus activated is thus the same as the thing' (*De anima*, III 7, 431B21). Thus 'the mind that is active is the objects' (*De anima*, III 7, 431B17). And the soul, the *psuchē*, the mind entails a *capax omnia* – for the soul is 'somehow all things'.

With regard to this desirous faith, Augustine implores us, 'believe so that you may understand' *(crede, ut intelligas)*. Aristotle concurs: 'Some trust is necessary

18. The term *curiositas* was coined by Cicero. The Latin term stems from the Greek words *periergos* and *polupragmon* (see Torchia 2013).

19. Clement, I Epist. Ad Corinth, 37.4. This echoes a passage from the Hippocratic book – *Peri trophés* 23: 'One confluence, one conspiration, all in sympathy with one another!'.

for whoever wants to learn *(dei pisteuein ton manqanonta)*' (*Sophistical Refutations*, 2, 165b3). *Scientia* realizes that all sciences are subalternate, that is, they live by way of borrowed logics of which they cannot give an account. As Aquinas pointed out, theology as *sacra doctrina* must borrow from revelation (e.g. knowledge of the Trinity), likewise physics borrows from mathematics, or the example given by Aquinas is that of optics. Once again, this is the simultaneous moments of the cataphatic and the apophatic which all knowledge entails. Therefore, all *scientia* is a *marriage* of discourse, a concert of effort that forfeits imperial ambitions, for *scientia* seeks engagement, not subsumption, nor eradication. It is a marriage that does not seek the purely isolated, or the reduced. Maybe the person of *scientia* is imbued with what the poet Keats called 'negative capability' (Shakespeare was one person he had in mind), 'when man is capable of being in uncertainties, Mysteries, doubts, without any irritable reaching after fact & reason' (Keats 1958, 193). This is reminiscent of Rilke's reading of Orpheus: 'Song, as you teach it, is not covetousness, or the quest for something one might fully obtain. Song is existence' (Rilke 2015, 29). Our common universe, such an uncommon song.

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