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Hannes Leitgeb
Ilkka Niiniluoto
Päivi Seppälä
Elliott Sober
Editors



12 Prospects for an integrated history and philosophy of composition

HASOK CHANG *

Abstract. I propose a new line of argument against metaphysical reductionism, focusing on the actual practices of composition and decomposition in chemistry and physics. Such a focus exposes significant problems with the common assumption that every material entity is made up of smaller units in a straightforward way. In the early days of chemical analysis there were worries that the analytical techniques might be altering the substances being analyzed, rather than simply taking them apart. In those reactions where molecules seemed to be cleanly dissociated into smaller units, the latter most often turned out not to be atoms. Such worries are reproduced and amplified when we consider the practices of modern nuclear and particle physics. “Atom-smashing” has never been Lego-like disassembly, since mass is not conserved in nuclear disintegrations. Generally, experiments in high-energy physics do not produce results that are in line with the naïve philosophical view of reductive levels, as illustrated very well in proton–proton collisions and pair-creation/pair-annihilation events. Compositionism, namely the notion that things are made up of stable units that persist through reactions, has been strongly discredited by developments in chemistry and physics. This fact of scientific practice argues against a simple-minded application of mereological principles to physical composition. But why are there such widespread intuitions in favor of metaphysical reductionism in the manner of mereology? I argue that the source of such intuitions is our predilection for compositionist analysis, for

*Department of History and Philosophy of Science, University of Cambridge.

the conduct of which the compositionist principles hold a quasi-Kantian conceptual necessity. We do apply compositionist analysis successfully in many areas of mathematics and some areas of science and everyday life. However, it is unwise to let ourselves be guided by these intuitions in situations in which attempts at compositionist analysis show little evidence of empirical success.

Keywords: reductionism, microreductionism, composition, analysis (chemical), ontological principles, conservation.

1 Introduction

In this paper I would like to propose a new line of argument against metaphysical (or ontological) reductionism. Following John Dupré, Nancy Cartwright and others, my approach is based on a commitment to respect the best scientific practices and their outcomes, while not renouncing philosophical judgment. There is nothing particularly new in taking a naturalistic approach, but the particular kind of focus I seek to give is not on the verdict of theory on what the world is like, but on the nature of the actual laboratory operations through which entities are (presumably) broken down into their components and synthesized again from their components. If we want to talk seriously about the composition of objects and substances, I think we need to pay close attention to what happens when we actually break things down and put them together.

The gist of my argument will be that successful analytic and synthetic practices in chemistry and physics do not fit the Lego-like picture of decomposition as clean dissection, and composition as simple assembly of unchangeable units. If my argument is correct, we must ask where the widespread reductionist intuitions come from, and to what extent they can be justified or trusted, if at all.

A brief comment about how I came to think about this topic might be helpful, self-indulgent as it may be. In my previous work I have made various arguments concerning reductionism and realism, but only from an epistemic point of view. However, recently I have come to concede that it is unavoidable to enter into some metaphysics if I want to make my epistemic positions truly coherent. This paper is one of my first attempts to grapple more seriously with metaphysical issues.¹

My thinking on reductionism began by following one line from John Dupré's early arguments: even if we grant ontological reduction, epistemic reduction does not follow. With an eye on some classic reductionist positions, Dupré focused on "compositional reductionism" or "microreductionism", which he understood as "the view that the ultimate scientific understanding of a range of phenomena is to be gained exclusively from looking at the constituents of those phenomena and their properties." (Dupré,

¹Another attempt is Chang (2016). The epistemological arguments that have led me to the issues discussed in the present paper are contained in Chang (2015).

1993, p. 88.) There are many ways to argue against such a view, even while we accept that things are made up of smaller things and everything can be smashed up into elementary particles ultimately. There are different observational terms at different levels, and different abstractions and idealizations that are effective at different levels; if one smashed up a plate and smoothed out the rough edges on the pieces, one could not reconstitute the original plate by putting the smoothed-out pieces together. It is also important to note, following Dupré again, the general mismatch between functional and structural categories, and the lack of a guarantee that structural analysis will be informative of the nature of functionally defined entities (e.g. chair, hemoglobin).

I used to think that the above points spelled an effective end to the reductionism debate: we can accept ontological microreduction, but epistemic microreduction does not follow. But I now think that it is equally important to subject ontological microreductionism to full critical scrutiny. Dupré gives some arguments against the hierarchical compositional ontology assumed in reductionist scheme, given by Paul Oppenheim and Hilary Putnam for example (1958, p. 9): (1) Elementary particles; (2) Atoms; (3) Molecules; (4) Cells; (5) (Multicellular) living things; (6) Social groups. I want to push those arguments further, and also take them to the heart of the presumed reductive base, namely to the realm of chemistry and then physics. I want to question seriously the commonly accepted assumption that everything can be smashed up into smaller and smaller parts, ultimately down to elementary particles, in any straightforward sense. My motivation for questioning that ontological microreductionist assumption comes not from any metaphysical investigations, but from my studies in the history of chemistry and physics.

2 The history of decomposition: Analytical chemistry

Let's start with chemistry. The practice of decomposing substances into their presumed components began in analytical chemistry centuries ago, long before physicists were attempting any such thing (perhaps with the exception of Newton's optical experiments). But a careful look at the history of chemistry reveals that decomposition has always been a contentious sort of practice. In the early days of chemical analysis, there were worries that the processes of alleged decomposition might be altering the substances being analyzed or even creating new ones. There was a very long tradition of "fire analysis" in alchemy and chemistry. It was a common observation that the application of strong heat tended to break things down, and a common chemical practice to study the composition of complex substances by dry-distillation or other techniques. But the cogency of fire-analysis was questioned by the likes of Robert Boyle (see Debus, 1967). How could one be sure that the application of fire was merely breaking things up into their constituents, rather than altering their very nature – or having the particles of fire sticking to them? Similar kinds of doubts were raised even more obviously concerning other methods of chemical analysis, such as

the dissolution of substances by the application of acids.

Overcoming these doubts enabled the establishment of what I have called “compositionism” in chemistry, starting from the late 18th century, most notably with the line of development going from Lavoisier to Dalton. Compositionism, as an ontological doctrine, is the notion that chemical substances are made up of stable units that persist through chemical reactions (see Chang, 2012, chapter 1, and for more detail, Chang, 2011). This idea also grounded the understanding of chemical reactions as the rearrangement of distinct and stable building-blocks which retain their identity (even when their properties are not manifest in a state of combination). This idea can also be extended beyond the realm of chemistry, as we will see later.

An important part of the compositionist tradition of chemistry was Lavoisier’s operational definition of chemical elements:

... if, by the term *elements*, we mean to express those simple and indivisible atoms of which matter is composed, it is extremely probable we know nothing at all about them; but, if we apply the term *elements...* to express our idea of *the last point which analysis is capable of reaching*, we must admit, as elements, all the substances into which we are capable, by any means, to reduce bodies by decomposition. (Lavoisier, 1789/1965, p. xxiv.)

In Jean-Antoine Chaptal’s more compact formulation, Lavoisier’s definition amounted to taking “the endpoint of analysis” as elements.² The point of such a conception of elements was to identify the building-blocks of chemical substances that one could actually work with in the laboratory. Such a hands-on notion of units enabled the articulation of a practical ideal in the study of the constitution of matter, which consisted in one’s ability to take things apart and put them back together — or, for analysis and synthesis, or decomposition and recomposition.

But this was hardly the end of ontological doubts. In order to apply Lavoisier’s definition, we need to know how to tell which chemical operations are decompositional. That requires us to know whether the products of a chemical operation are simpler than the ingredients going into it. But the whole point of the analytical definition of chemical element was to define elementarity (or simplicity) in terms of decompositional operations, so we are caught in a tight circularity: what are elements (or, simple substances)? — those that cannot be decomposed further — what are decompositional operations? — those that produce simpler substances. This circularity threatens to make the analytical definition of elements operationally empty. The difficulty can be illustrated quickly through a couple of examples from the Chemical Revolution (see Chang, 2012, chapter 1, for a detailed treatment). Is sulfur an element? The phlogiston theorists didn’t think so, because they thought (and showed by experiment)

²J. A. Chaptal, *Elemens de Chymie*, 3rd ed., 1796, vol. 1, p. 55 (quoted in Siegfried & Dobbs, 1968, p. 283).

that it could be decomposed into sulfuric acid and phlogiston. The Lavoisierians disagreed, arguing instead that sulfuric acid was a composite substance, which they could decompose into sulfur and oxygen. Are metals elements? The phlogistonists didn't think so, as they knew how to decompose them into calxes and phlogiston. Again, the Lavoisierians saw the same reaction as a synthetic one, in which the metals combined with oxygen and formed oxides.

Readers who know something about this history will be thinking that Lavoisier solved this problem by the weight criterion. When a metal oxidizes, the rust is heavier than the metal, and moreover the weight of the rust is equal to the sum of the weights of the metal and the oxygen. Isn't it clear from these facts that the rust is composed of the metal and the oxygen? That is indeed how the circularity was broken, at least to Lavoisier's own satisfaction. But the matter was not so simple. The precision of Lavoisier's chemical accounting was much exaggerated (for example, witness his utter confidence that the weight-ratio of hydrogen and oxygen making up water was 15:85 precisely, rather than roughly 1:8). More importantly for the purpose of the present paper: who decided that weight was the magic criterion for telling the composition of substances? Phlogiston was generally considered weightless, and Lavoisier's own chemistry was based on the notion of caloric, namely the substance of heat, which was weightless. Even if we disregard the weightless substances, weight as the criterion of composition only works if we assume that weight (or mass) is conserved – we now know it is not – but now I am getting ahead of the story.

Set aside all of those questions and doubts. What is even more important is the fact that, as compositionist chemistry unfolded, it became clear that most of the useful analytical techniques did not involve simple, clean decompositions. Take water, the highlight of Lavoisier's triumph in the Chemical Revolution. Lavoisier never actually came up with a method of simply decomposing water into hydrogen and oxygen. What he did do was to pass steam over very hot iron (a gun barrel), which resulted in the rusting of the iron and the production of hydrogen gas; he presumed that the oxygen from the water (steam) must have combined with the iron, but he was never able to get the oxygen in pure form from water. In fact most decompositional operations in chemistry at that time was of this "sticky" form: not $[AB] \rightarrow [A] + [B]$, but $[AB] + [C] \rightarrow [AC] + [B]$, or worse.

In the case of water, the first clean separation of it into its constituents (i.e., hydrogen and oxygen) was only achieved in 1800, several years after Lavoisier's death, thanks to Volta's invention of the battery, which quickly led to the first electrolysis of water by William Nicholson (with Anthony Carlisle).³ This is represented in a modern rendition in **Figure 1**.⁴ But when this clean decomposition was achieved, the earlier

³There was a previous decomposition of water by electric sparks, but in that case the hydrogen and oxygen gases were produced in a mixture.

⁴I take the figure from Pauling and Pauling (1975, p. 357). Note an error in the volumes of hydrogen and oxygen in the figure, which should be in a 2:1 ratio. (Lesson: always check your page proofs.)

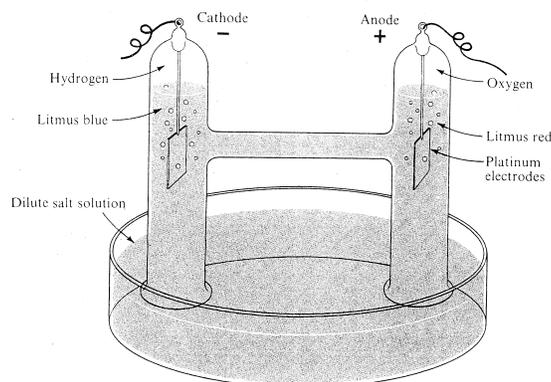


Figure 1. A modern view of the electrolysis of water.

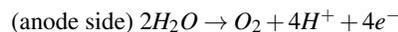
circularity between simplicity and composition came back. First, note a quandary that Nicholson himself admitted right from the start: if electrolysis was the decomposition of each water molecule by the application of electricity, why did the oxygen and hydrogen not originate from the same spot where the water molecule would have been? This difficulty, which I have called the “distance problem”, threatened to overturn the basic Lavoisierian interpretation of the composition of water. Johann Wilhelm Ritter understood the same electrolysis experiment as a pair of *syntheses*: hydrogen from water and negative electricity at the negative electrode, and oxygen from water and positive electricity at the positive electrode. And this interpretation, annoyingly for Lavoisierians, lined up exactly with Henry Cavendish’s latter-day phlogistonist interpretation, if one identified phlogiston with negative electricity (see **Table 1**). No one denied at the time that electricity was a substance, and what exactly happened ontologically in electrolysis was at best contentious at that time, and subsequently for most of the 19th century. What happened to the distance problem in the end is too long a story to include here (see Chang, 2012, chapter 2), but the point here is that the chemical reaction itself did not carry its own obvious compositional interpretation.

Let us just assume, for now, that the circularity was eventually overcome. That is to say, I’m now just going to stick with the story of what happens in these reactions as accepted in modern chemistry, in terms of atoms and molecules. But that modern picture still embodies some fundamental difficulties for ontological reductionism. When chemists did manage to make clean decompositions of molecules, the smaller units produced often turned out not to be atoms. That is not necessarily a problem for microreductionism in general, but at least inconvenient for the usual hierarchical picture as presented by Oppenheim and Putnam.

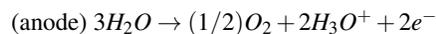
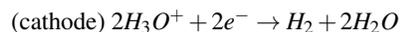
Table 1. Competing views of the composition of water.

<i>We observe:</i>	Inflammable air	and Vital air	combine, to make	Water
<i>Lavoisier says:</i>	Hydrogen	Oxygen	→	H-O [compound]
<i>Cavendish says:</i>	Phlogisticated water	Dephlogisticated water	→	Water [element]
<i>Ritter says:</i>	Negatively electrified water	Positively electrified water	→	Water [element]

Think about water again. What actually happens, in modern terms, when we break up a molecule of water? H_2O never breaks up into two atoms of hydrogen and one atom of oxygen. If the decomposition is done by ionic dissociation (which happens spontaneously even in pure water), H_2O breaks up into H^+ and OH^- . If it is done by electrolysis, $(2)H_2O$ breaks up into $(2)H_2$ and O_2 . If actual decomposition is what tells us about the building-blocks, then hydrogen and oxygen atoms are not the building-blocks of water. As it turns out, the stable units in chemical reactions are often not atomic (e.g., H^+ and H_2 , not H). If we ask what really happens in the electrolysis of water, the picture is not simple, and not completely agreed among 20th-century chemists, either. In Pauling and Pauling's view, shown in **Figure 2** (Pauling and Pauling, 1975, p. 356), H_2O molecules first gain or lose some electrons, ending up as H_2 and O_2 molecules, as well as H^+ and OH^- ions. In chemical formulas we have:



From the resulting products, $4OH^-$ and $4H^+$ combine again to make $4H_2O$ molecules. The $4e^-$ on the left-hand side of the first equation represents the input of electrons from the battery through the cathode, and the $4e^-$ on the right-hand side of the second equation represents the flow of electrons into the battery through the anode. In another well-known textbook, by David Oxtoby et al. (1999, p. 432), the story is similarly complex, but not quite the same as the one given by Pauling and Pauling:



Adding the two equations together, we can see the whole reaction as one measure of H_2O breaking up into one measure of H_2 and half a measure of O_2 . In neither case do we have simple decomposition into atoms, or even simple re-constitution of atoms from pre-existing ions.

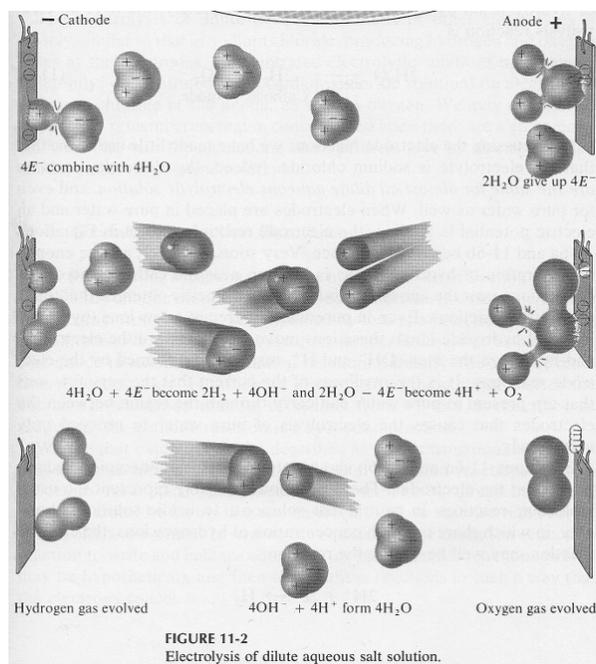


Figure 2. *The electrolysis of water, in Linus Pauling and Peter Pauling's interpretation.*

It may be easy to say, and it may have been almost universally agreed, that water is made up of oxygen and hydrogen. But it is quite difficult to translate that into a truly reductionist compositional statement, such as " H_2O is made up of H_2 and O_2 " or " H_2O is made up of H and O ." The former is not true in any rigorous metaphysical sense, and the latter is never realized in decompositional (or compositional) laboratory practice. Generally speaking, decomposition is not often instantiated in the practice of chemistry in any way that would satisfy the standard reductionist picture of composition. In the end, no laboratory practices in chemistry have been able to effect the kind of decomposition into atoms that Dalton's diagrams such as the one shown in **Figure 3** (Dalton, 1808, Plate 5, opposite p. 560) and other similar depictions lead us to imagine. In the 20th century, the advanced practices of analytical chemistry have moved on to spectroscopic techniques including nuclear magnetic resonance (NMR), in the employment of which no molecules are decomposed at all (see Reinhardt, 2006 for a detailed account of these developments).

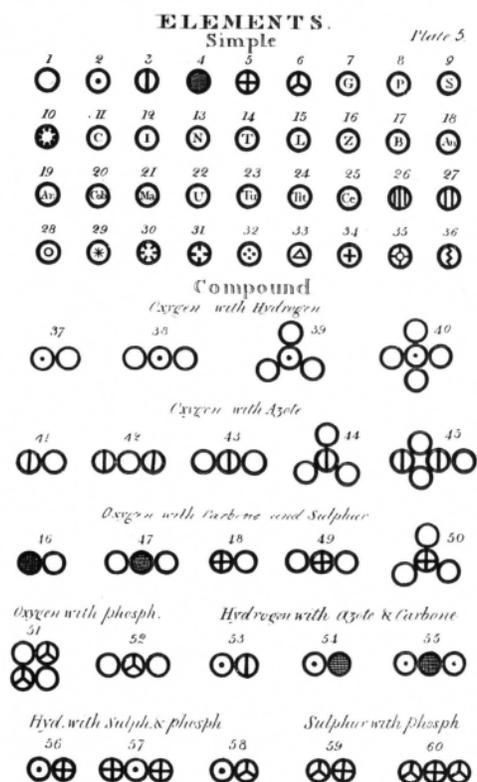


Figure 3. John Dalton's atomic diagrams.

3 The history of decomposition: Modern experimental physics

At this point I anticipate the response that of course chemistry is a mess, and reductionist science made real headway only with the advent of modern physics. If we look briefly again at the composition and decomposition of water, the presence of H^+ (proton) and e^- (electron) in the reactions clearly indicate that what we need here is elementary particles, not the outmoded notion of Daltonian atoms. So we must take a look at the atom-smashing practices of modern experimental physics, and see if they can provide some reassurance to the ontological reductionist. Here I am only going to rely on very rudimentary modern physics, the kind that has been very much taken for granted for many decades now, as that will be sufficient for my current purposes.

There should not be anything controversial about any of the physics that I will be discussing, and any physicists reading this may wonder why I am taking pains to state the obvious.

The philosophically interesting thing here is that the same kinds of worries about compositionist reductionism that we saw in the history of chemistry are reproduced anew, and even amplified further, when we consider the practices of modern nuclear and elementary particle physics. “Atom-smashing” has never been Lego-like disassembly: when atomic nuclei are broken up, energy is almost always added or subtracted, and according to modern physics mass is a form of energy. In nuclear reactions experimental physicists have taken careful note of the interconversion of mass and energy. It won’t do to suggest that the Lego-like picture is approximately true since the amounts of mass lost or gained in these reactions are relatively small compared to the total mass of the reactants: no theory that has to dismiss nuclear bombs as merely inconvenient anomalies should be regarded as “approximately true” in the relevant sense.

Let’s think a little bit further about the history of mass-energy equivalence. $E = mc^2$ came out of Einstein’s special theory of relativity, which was accepted for very general theoretical reasons, but we might ask what experimental evidence compelled people to believe this particular aspect of the theory. In this context, what is invoked most often are particle-collision experiments in which the masses of the ingredients do not add up exactly to the sum of the masses of the products (see Fernflores, 2012, esp. Section 4). Especially famous is the 1932 experiment of John Cockcroft and Ernest Walton, who bombarded a lithium nucleus with a proton and obtained two helium nuclei (α -particles). Their measurements showed that the sum of the masses of the reactants was $1.0072 + 7.0104 = 8.0176$ amu,⁵ but the masses of the products only added up to 8.0022 amu, indicating that 0.0154 amu has “disappeared.” After over a century of dominance, Lavoisier’s principle of the conservation of mass had been overturned in physical and chemical practice. An inspection of the periodic table of elements also easily shows that the masses of atoms are slightly different from the masses of the protons and neutrons (and electrons) that constitute them. These have been regarded as indisputable facts for many decades now by physicists and chemists, but the basic metaphysical implications of such facts have not got through to the sensibilities of reductionists. If we still regard mass as the primary indicator of the amount of matter, then it is clear that the amount of matter is not preserved in elementary-particle collisions or nuclear fusion or fission. That does not present a problem for the conservation of energy, of course, but it does destroy the naïve notion that atoms are simply put together from elementary particles. Atomic nuclei are not mereological sums of protons and neutrons; they are not made up of protons and neutrons in a straightforward sense.

Generally speaking, the results of experiments in high-energy physics do not support the naïve philosophical view of reductive levels in the Oppenheim–Putnam mode,

⁵1 amu (atomic mass unit) is 1/12 of the mass of carbon-12 in its ground state.

according to which atoms are made up of elementary particles, which are themselves unchangeable building-blocks. When two protons collide with each other in a particle accelerator, a whole host of other particles are created:⁶ should we say that a proton already contained these particles? Should pair-creation and pair-annihilation lead us to conclude that a pair of photons consist of an electron and a positron, or *vice versa*?⁷ When a photon is absorbed by an atom, it is annihilated and raises the energy level of the atom; so the photon is not an unchangeable unit, not even a persisting one. These are merely a handful of illustrative examples. Generally speaking, smashed-up pieces do not necessarily pre-exist in the whole. This recognition led Geoffrey Chew to advance his “bootstrapping” view of elementary particles, according to which no particles are fundamental and all elementary particles are made up of each other.⁸ This view was sidelined with the advent of quarks and the Standard Model, but it may be worth revisiting, after all. The early modern chemists’ mereological fears have turned into reality “with a vengeance”, in much more serious ways than they could have imagined. There is no need for “the Tao of physics”, but there are good reasons to have our metaphysical thinking informed by respect for actually viable practices.

Again, I must stress that all of what I have discussed in this section is based on *obvious* physics. I do not claim any special knowledge of modern physics, and I am not drawing from any controversial parts of physics. The experimental facts that I cite are very well-known and accepted in an unquestioning way by physicists. I am not even invoking the difficult ontological questions raised by the notion of quantum superposition and entanglement, or indistinguishability, or virtual particles and vacuum fluctuations, or quark confinement, which are bound to complicate the picture much further and in all likelihood in anti-reductionist directions.⁹

4 Scientific naturalism, everyday intuition, and conceptual habits

At this point some philosophers may say: “But what these physics experiments (or the theories created in order to explain them) seem to show can’t really be the true metaphysical picture. There *must be* unchangeable basic building blocks, and everything must ultimately be made of them.” Of course, no amount of scientific knowledge would *prove* that the metaphysical reality is not like Lego. I think that way of thinking

⁶See a friendly presentation of the basic facts and ideas in the “International Physics Masterclasses” section on proton collisions (http://atlas.physicsmasterclasses.org/en/zpath_protoncollisions.htm).

⁷Positron–electron pair-annihilation is now even in the realm of everyday technology as the basis of PET (positron-emission tomography) scans; it is not something we can afford to ignore in our thinking about the world.

⁸For more on the metaphysics of bootstrapping and the S-matrix theory, see McKenzie (2011).

⁹For a cutting-edge discussion, see Caulton (2015).

about reality is not productive, but that is not the argument I am making in this paper. For now I want to focus on a different question: where do people get the intuition that reality is Lego-like?

(1) Old science. In the discussion above I have implied that philosophical reductionists are quite out of step with modern science. So could it be that the reductionist intuitions come from some older phase of science that was once successful, from which we've inherited some now-outdated theoretical assumptions, which parade as metaphysical intuitions? This sort of situation has been common in the history of science. As Philipp Frank put it (1949, pp. 475, 478): "the Copernican system was declared to be 'mathematically true' but 'philosophically false.' And this severe judgment has been passed again and again by philosophers upon new physical theories." Such impulse is understandable, but it is something we need to learn to overcome: "We understand now very well that these 'established philosophic principles' are nothing else than physical hypotheses in a state of petrification."

In this case, however, I do not think that successful past science can be a full explanation of our intuitions. It is true that *some* Lego-like science has been successful: e.g., 19th century organic structural chemistry. I think such cases did have some effect on creating, or at least bolstering, compositionist intuitions. But there are some significant caveats that negate this point almost entirely. (a) A lot of other successful science (such as 20th-century physics) has not been compositionist. (b) A lot of compositionist science has been unsuccessful; for example, Alan Chalmers (2009) has shown persuasively that much of early atomic science was rather useless. (c) Compositionist ideas were widespread and popular long before there was successful compositionist science; Democritus, or even the 17th-century mechanical philosophers, would not have got their atomistic ideas from some successful previous science. (d) Even successful compositionist science often showed awareness that physical reality was not entirely compositionist. The "ball-and-stick" molecular models needed the sticks to connect the balls, and it was recognized that the sticks were exactly the mysterious part of the picture: the nature of the chemical bond remained enigmatic throughout the 19th-century except in clear cases of ionic bond.¹⁰

(2) Everyday life. It could be that the compositionist intuitions are rooted in our everyday life, rather than in successful previous sciences. Robert Northcott, in a serious joke, comments that we must have such intuitions because we all grew up playing with Lego. Lego itself was not invented till 1949 so it can't have been responsible for the advent of compositionism, but could it be that much of our everyday life, dealing with "medium-sized dry goods" is like playing with Lego, giving rise to compositionist intuitions? We can smash a plate and glue it back together, build a house out of bricks, and take apart a watch and put it back together.

But these practices of composition do not work in Lego-like ways. When we try to put

¹⁰Cohesion was a similar mystery. For a fascinating history of cohesion, see Rowlinson (2002).

things together in everyday life, it does not normally work out in the compositionist way. Medium-sized dry goods generally do not stick to each other. Bricks need mortar to make a wall or a house. What we know of as “Lego”, first marketed as “*automatic binding blocks*”, was such a commercial and cultural success precisely because it was a very clever arrangement, an ingenious combination of rigidity, elasticity and friction, in which bricks do stick together without the help of anything else!¹¹ Almost nothing else in nature or human life behaves like Lego,¹² and that is the secret of its success. We do not live in Legoland. Where *do* we live? Our quotidian paradigm for sticking things together is the use of glue. How glue works is not at all like Lego, so our experience of gluing (or stapling, or clamping, or strapping) things together does not explain why we have Lego-ish intuitions.

(3) Quasi-Kantian conceptual necessity. I suggest that that our compositionist intuitions come not from practical experience, but from a quasi-Kantian conceptual necessity. I say quasi-Kantian because the necessity involved here is conditional (paradoxical as that may sound), being consequences of definitions that we happen to adopt. More generally, ontological principles (as I term them) are assumptions that we have to adopt about the presumed entities that we are dealing with, if we are to carry out certain kinds of epistemic activities. It is our choice to engage in a particular epistemic activity; once we have made that choice, however, there are some metaphysical assumptions we must subscribe to, because they are necessary for that activity to be successful or even intelligible. For a very simple example: if we want to engage in the activity of counting, then we have to presume that the things we are trying to count are discrete. In other words, the metaphysical principle of discreteness is required in the activity of counting, and enables that activity. What we have here is a distinct type of a transcendental argument — laying out the necessary conditions for something that we may or may not choose to do, rather than investigating the precondition of what is already and definitely given. So I think of it as a contingent transcendental argument in the form: “*if we want to do X, then we must presume Y.*”¹³

In illustrating these ideas briefly, it is helpful to refer back to the work of the much-neglected Clarence Irving Lewis. In a move that is only apparently anti-Kantian, he denies that there are any synthetic *a priori* principles. For Lewis all *a priori* principles follow from the nature of the concepts we choose to craft and use:

The paradigm of the *a priori* in general is the definition. It has always been clear that the simplest and most obvious case of truth which can be known in advance of experience is the explicative proposition and those consequences of definition which can be derived by purely logical anal-

¹¹For the history of Lego as told by the company itself, see http://www.lego.com/en-us/aboutus/lego-group/the_lego_history/1940.

¹²Gretchen Siglar points out that Velcro is similar.

¹³The nature of a contingent transcendental argument is explained in full in Chang (2008) and Chang (2009).

ysis. These are necessarily true, true under all possible circumstances, because definition is legislative. (Lewis, 1929, pp. 239-240.)

And yet, Lewisian *a priori* principles in science are not mere tautologies; they do serve as significant laws of nature, in a way that I think is consonant with Michael Friedman's views on what constitutive principles do (Friedman, 2001). Lewis chose Einstein's definition of simultaneity in special relativity to help make his point about the role of definitions:

As this example well illustrates, we cannot even ask the questions which discovered law would answer until we have first by *a priori* stipulation formulated definitive criteria. Such concepts are not verbal definitions nor classifications merely; they are themselves laws which prescribe a certain behavior to whatever is thus named. Such definitive laws are *a priori*; only so can we enter upon the investigation by which further laws are sought. (Lewis, 1929, p. 256.)

Finally, let me come back to the matter of composition. I submit that compositionist intuitions are ontological principles necessitated when we choose to carry out compositionist analysis, by which I mean the the activity of understanding an object as a mereological sum of its parts, each of which persists unless broken up into its own parts. So compositionism, now generalized from the sense I gave it in the context of chemistry, can be re-stated as the metaphysical doctrine that all objects are made up of persisting parts, whose identity is not affected by any combinations into which they enter. To this basic compositionist assumption, scientists and philosophers often add two further ideas, which are actually not necessary for compositionist analysis *per se*: (1) that there are fundamental parts that cannot be further decomposed, and (2) that there are only a small number of types of fundamental parts (units).

If we choose to carry out a compositionist analysis, it makes no sense not to adopt the basic compositionist ontology; that would render our activity incoherent and unintelligible. And if we do routinely carry out compositionist analysis, we may understandably form compositionist habits of the mind. We often do engage in some compositionist analyses in the activities of everyday life. Simple-minded accounting is a very good example; money is a wonderfully compositionist entity, which can be divided and added up with no loss or change of any presumed parts. We also engage in compositionist analysis in theoretical science, for example when we apply various conservation laws, or when we learn to divide and add up angles or lengths in geometry. Perhaps most fundamentally, the standard kind of arithmetic that most of us are taught in childhood is firmly founded on compositionist intuitions. The experience of such epistemic activities gives us familiarity with compositionist ontological principles, and disposes us to think in compositionist terms.

However, this is not to say that we *should* always engage in compositionist analysis. And it is incoherent to try to reason on the basis of compositionist intuitions when we are not in fact carrying out any compositionist analysis. Similarly, it is futile to attempt a compositionist analysis where we cannot find reliably persistent units out of

which the objects of our interest can be said to be made. Whether or not there are such units is an empirical question, a contingent matter, which can only be clarified in an operational way, by devising and attempting to carry out actual operations of physical assembly and disassembly.

It is a mistake to make an unthinking application of mereology to physical combination. Judging from the findings of modern chemistry and physics, it seems that the mereological part-whole relation is an inappropriate framework for understanding physical combination. Physical fusion and disintegration may violate axioms that one considers reasonable or even indispensable in mereology, such as transitivity. If so, the most reasonable conclusion may be that physical composition is not a matter of part-whole relation. We need to make sure that quasi-Kantian conditional necessity does not degenerate into pseudo-Kantian metaphysical prejudice.

5 Conclusion

Attention to the actual practices of chemistry and physics reveals that there has never been unequivocal scientific warrant for ontological reductionism as it is commonly conceived. And if ontological reductionism doesn't work in chemistry and physics, then it is not likely to work in other sciences, partly because the usual reductionist strategy concerning those other sciences is to reduce entities in them to the entities of chemistry and physics. The main source of widespread intuitions in favor of ontological reductionism is neither everyday life nor successful past science. Rather, it is our predilection for compositionist analysis, which we apply successfully in many areas of mathematics and some areas of science and everyday life. But it is unwise to let ourselves be guided by these intuitions in other situations, especially those in which attempts at compositionist analysis show little evidence of empirical success.

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Author biography. Hasok Chang is the Hans Rausing Professor of History and Philosophy of Science at the University of Cambridge. He received his degrees from Caltech and Stanford, and has taught at University College London. He is the author of *Is Water H₂O? Evidence, Realism and Pluralism* (2012), and *Inventing Temperature: Measurement and Scientific Progress* (2004). He is a co-founder of the Society for Philosophy of Science in Practice (SPSP), and the Committee for Integrated History and Philosophy of Science.