



Chemistry, an ontology-free science?

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Chemistry, an ontology-free science?

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Abstract

It is often assumed that chemistry was a typical positivistic science as long as chemists used atomic and molecular models as mere fictions and denied any concern with their real existence. Even when they use notions such as molecular orbitals chemists do not reify them and often claim that they are mere models or instrumental artefacts.

However a glimpse on the history of chemistry in the *longue durée* suggests that such denials of the ontological status of chemical entities do not testify for any specific allegiance of chemists to positivism. Rather it suggests that the dilemma positivism vs realism is inappropriate for characterizing the ontology of chemistry. This alternative shaped at the turn of the twentieth century in the context of controversies about atomic physics does not take into account the major concern of chemists, i.e. making up things. Only by considering what matters for chemists, their matters of concern rather than their matter theories, can we expect to get an insight on their ontological assumptions. The argumentation based on historical data is twofold.

Generating new substances out of initial ingredients which is the *raison d'être* of chemistry raised a vexing puzzle which has been alternatively solved with the Aristotelian notion of mixt and the Lavoisieran notion of compound. I will argue that an essential tension remains intrinsic in chemistry between the two conceptual frameworks.

But how are we to make sense of the long tradition of ontological non-commitment in chemistry? I argue that what is usually considered as a denial of the existence of the basic units of matter is better characterized as a focus on more important actors on the chemical stage.

The chemical puzzle

Paul Needham who gave detailed analyses of Aristotle's conception of mixts convincingly argued that Aristotle raised the fundamental issue of chemistry. The issue raised by Aristotle in *De generatione et corruptione* I, concerned the mode of presence of the constituents in a mixt. The problem emerged from a critical review of atomism. If atomist doctrines were right, then a mixt would be just a collection of atoms placed side by side, like grains of wheat and grains of barley. "To the eye of the Lynceus nothing would be combined".¹ Constituents would be physically present in the compound although not visible at first glance. They can be recovered without changing the properties of the compound. However Aristotle insisted that if the ingredients are preserved then the mixt is only apparent. By contrast a true process of mixing involves the interaction of qualitatively differentiated ingredients in such a manner that they do not persist unchanged in the resulting compound. A true mixt is not just constituents sticking together. Something new is created, with properties not possessed by the original ingredients. The emergence of a new stuff implies that the ingredients no longer coexist with the mixt. Consequently a true mixt can be characterized by an **either...or** condition. Either you get a compound, and you lose the properties of the initial ingredients; or you recover the original ingredients and you lose the properties of the mixt. By contrast, the atomic conception of chemical combination does not require such a disjunction.

However Needham's clear recognition of the importance of the Aristotelian puzzle for chemistry does not allow to claim that Aristotle had shaped a "theory of chemical reaction and chemical substances",² for chemistry did not exist as an identifiable branch of knowledge in his time.

Avoiding such anachronisms is important for grasping the presence of what I dub an "essential tension" between two competing views of chemical combinations that both shaped the identity of chemistry.

Between mixts and compounds, between Stahl and Lavoisier

At the turn of the eighteenth century, Georg-Ernst Stahl echoed Aristotle distinction between true and apparent mixts in an attempt to delineate the territory of chemistry from that of physics. Aggregation was a juxtaposition of units, and could be understood in mechanical terms such as mass and movement. Mixtion was the union of principles involving individual affinities. The decomposition of an aggregate would not affect its properties whereas mixts could only be analyzed by changing their properties. Stahl thus centered chemistry on the notion of mixt, against tentative annexations by mechanism. So successful was this conceptual strategy, that Stahl has been celebrated as the founder of chemistry throughout the eighteenth century.

¹ Aristotle, *De generatione et corruptione* I.10, 328^a13f)

² Needham 1996, 2006.

However one century later, chemists no longer used the word ‘mixt’, as the notion of composition prevailed. In particular, Lavoisier’s famous definition of elements as non-decompound substances was integral part of a reorganization of chemistry along the backbone of another conceptual distinction, between simple and compound. Lavoisier, who came to be celebrated as the founder of “modern chemistry”, in reality redefined chemistry as the science aiming at decomposing the natural bodies and “examining separately the various substances entering in their combination”.³ To be sure the compositional perspective was nothing new, but it became the dominant paradigm with the reform of chemical language.⁴ In the new language names of compounds were coined by simple juxtaposition of their ingredients names.⁵ Lavoisier, who admired and extensively quoted Etienne Bonnot de Condillac’s *Logic*, adopted his views of languages as analytical methods as well as his notion of analysis as a two-way process, from simple to compound and from compound to simple. Condillac’s logic, inspired by algebra, in turn inspired Lavoisier’s use of equations to describe chemical reactions. A compound is described as the addition of two constituent elements. It is entirely characterized by the nature and proportion of its constituents. The use of the sign “equals” in the equation clearly indicates that chemists no longer care for the either/or condition. The puzzling issue raised by Aristotle about the mode of presence of ingredients in the compound has been ignored, simply discarded rather than being solved.

The compositional paradigm proved very successful when reinforced by John Dalton’s atomic hypothesis. By the middle of nineteenth century, the definition of a compound by the nature and proportion of its constituents has been challenged by a structural paradigm, taking into account the arrangement of atoms in molecules. However condensed formulas and structural formulas equally eliminate the either/or condition. The actual presence of constituent elements suffices to account for the properties of the compound.

Pierre Duhem’s return to Aristotle’s notion in the title of *Le mixte et la combinaison chimique* (1902) was clearly intended to undermine the compositional paradigm. Duhem mainly reproached atomistic explanations for assuming that the properties of compounds could be deduced from those of constituent elements or atoms. His criticism also encompassed Lavoisier’s notion of element as simple substance, since elements are not conserved as such in chemical reactions.

Emile Meyerson indirectly addressed the same issue although, unlike Duhem, he claimed that chemists could not dispense with the existence of atoms. He nevertheless pointed out the either/or issue involved in chemical equations. When chemists write the equation $\text{Na} + \text{Cl} = \text{Na Cl}$, they obviously presuppose the conservation of matter.⁶ However taken literally, a chemical equation is a non-sense. In assuming that the addition of a soft metal like sodium and a greenish gas like chlorine

³ Lavoisier (1789) second section, chapter “Sur le tableau des substances simples”

⁴ The compositional interpretation of the chemical revolution has been emphasized by Robert Siegfried and Betty J. Dobbs (1968)

⁵ Guyton de Morveau et al. (1787) p. 14.

⁶ Meyerson (1931) §54-55, p. 84-85

equates a colorless salt, chemists seem to be oblivious of the very conditions of their laboratory practice. Although they continuously play on the potentialities of various individual substances and take advantage of their differences, they admit that the compound “equals” the sum of initial ingredients.

“Surprising fact” is the phrase that Linus Pauling used to express a similar view in his elementary textbook *College Chemistry*: “That the substance salt is composed of a metal (sodium) and a corrosive gas (chlorine) with properties quite different from its own properties is one of the many surprising facts about the nature of substances that chemists have discovered”.⁷ Although he was a staunch advocate and propagandist of electronic theories of valence, Pauling still emphasized the Aristotelian puzzle and defined chemistry as the study of individual “substances”. “Chemists study substances, in order to learn as much as they can about their properties (their characteristic qualities) and about the reactions that change them into other substances”.⁸

There seems to be a tension between two conflicting views of chemical combinations that Meyerson described as a fight between the rational and the irrational, or as a contrast between a rational tendency and a more pragmatic tendency. After all, atomic theories do not hold the monopoly of rationality.⁹ Moreover, atomic notions, and molecular models are man-made “artifacts”, tools forged for theoretical and practical purposes.¹⁰ Nevertheless the tension is essential. None of the two perspectives is sufficient to account for chemical combinations. But the two descriptions do not work harmoniously together. Chemical combinations thus offer a new case of complementarity in Niels Bohr’s sense, i.e. two necessary and nevertheless exclusive descriptions of a phenomenon.¹¹

Denials or preferences?

Because chemists are not really concerned with understanding the fine structure of matter, they have often dismissed all hypotheses about the real existence of atom. For instance, August von Kekulé who conjectured the hexagonal structure of benzene, which was the basis of most artificial organic compounds manufactured by the end of the nineteenth century, denied the existence of atoms. More precisely, he rejected the ontological issue out of chemistry, as belonging to metaphysics. Thus chemists made an extensive use of atoms and molecular models while denying their existence or claiming that atoms were fictions. Even in the twentieth-century the ontological status of bonds and orbitals has been discussed among the founders of quantum chemistry. Some of them denied their physical reality in an effort to demarcate the chemical approach of concepts borrowed from physicists,

⁷ Pauling (1950) p. 4

⁸ Pauling (1950) *ibid.*

⁹ Meyerson convincingly argues that Stahl’s doctrine of qualitative principles was more rational than Lavoisier’s theory because Stahl assumed the conservation not only of the quantity of matter but also of qualities such as combustibility. See Meyerson, 1921 appendix II “The resistance to Lavoisier’s theory”.

¹⁰ Meyerson himself presented atoms as artefacts.

¹¹ Bohr (1958)

such as resonance for instance.¹² Chemistry thus appears as a science bound to ontological non-commitment by contrast with the attitude of modern physicists.

If we resist the temptation of identifying the philosophy of physics as the “right model” for all sciences, how are we to describe the strange attitude of unbeliever chemists?

For Meyerson, the chemists who denied the existence of atoms simply lacked authenticity.¹³ He claimed that all chemists professed a naive realism, a belief in the existence of things such as barium sulphide, for instance. Meyerson is right: chemistry is certainly not ontology-free. However he misunderstood its ontology. The assumptions underlying chemical practices do not concern things such as barium sulphide. More precisely, this sort of “thingism” (*chosisme*) is not typical of chemists.

Matters of concern

Two major matters of concern more adequately characterize their ontology: i) a concern for relations, and ii) a concern for action.

i) Relations

To be sure chemists deal with individual substances, and pay attention to their molecular structures. However these things are only of interest to them in so far as they enter in relations with other units. Nineteenth-century structural formulas were not meant as images of reality. They were not however pure conventions. Rather they displayed capacities of bonding, the so-called atomicity or valence. Ernst Cassirer convincingly argued that it is only apparently that an atom is considered as the “absolute substrate” of properties in chemistry. In fact, the concept of atom is just a mediator for mapping out a network of interdependent relations between objects.¹⁴

Gaston Bachelard also emphasized that chemists were concerned with relations rather with their substrate. Since relations imply at least two terms, chemistry necessarily presupposes various kinds of beings. Plural and relational are the two features that Bachelard selected to define the rationalism of modern chemistry that he dubbed “non lavoisian”.

If atoms for chemists are above all units capable of being related to other units, their physical reality is not a matter of concern. Georges Urbain could still consider atoms as fictions in the 1920s, although he had supported atomism against equivalentists. The fictional status was his way of emphasizing the specificity of the discipline of chemistry. In his view, atomic theories were just like tools in the hands of craftsmen so that two rival theories – such as energetism and atomism - could work together.¹⁵

The focus on relations allows chemists to chose the unit of matter that best suits their views. For instance, in Pauling’s valence bond theory, atoms are the combining units, and their interaction results in the formation of molecules. For Pauling, both double bonds and resonance were man-made

¹² Simoes, Gavrolu (2001)°

¹³ E Meyerson, Conférence du 23 avril 1911 sur « Evolution de la pensée allemande dans le domaine de la philosophie des sciences » p. 22. (archives A 408/11)

¹⁴ Cassirer (1910) chapter “Conceptualization in natural science”

¹⁵ Urbain (1921) p. 21-24 Later on in the 1930s, Urbain never adopted the electronic theories of chemical bond because he had forged an alternative theory of the chemical bond, based on Werner’s theory of complex that better suited his own practice of chemistry.

concepts. The theory of resonance involved “the same amounts of idealization and arbitrariness” as the valence-bond theory”. “The theory of resonance in chemistry is an essentially qualitative theory which, like the classical structure theory, depends for its successful application largely upon a chemical feeling that is developed through practice”.¹⁶ Thus time and again chemists claim originality through their rejection of the physical meaning of the concepts they are using while they play with all sorts of interactions to make things.

ii) Agencies

For chemists molecular structures are above all conditions of properties, which themselves are viewed as dispositions for desired or undesired performances. While chemists do not care for matter, they are looking for materials, i.e. substances useful for something. Remarkably eighteenth-century chemists used to present the four elements - fire, air, water and earth -, as natural instruments of the chemist’s laboratory, along with artificial instruments - menstrues and vessels.. Later on, although the compositional paradigm prevailed after the reform of chemical language, and the structural paradigm with the emergence of organic chemistry, chemical names and formulas have been mainly used as “paper tools” for predicting operations and substitutions.¹⁷ They display the possible uses of the compounds through their structure. This action-oriented language inspired Bachelard’s description of structural formulas as “rational substitutes”, providing a clear account of the possibilities for experimenting.¹⁸ Therefore nineteenth-century chemists could deny any ontological commitment with atoms and molecules, while using them just as plumbers use screws, nails, and joints. They refused to bestow the atomic theory with the power for representing the world, as they were concerned with powers for intervening. Atoms and molecules are just potential actors in chemical drama.

Ian Hacking’s comments on the way physicists use electrons typically suit the way chemists view the constituents of matter.¹⁹ Electrons are less explanatory notions, as they are instruments for acting or creating phenomena. Hacking’s distinction between “realism about theories” and “realism about entities” could thus apply to chemistry. To be sure, chemists are realists. They believe in the reality of entities, which allow them to operate on the outside world or to be affected by it. “Operational realism” would thus be the right phrase to characterize the chemists’ philosophy. The material world is a theater for operations; the entities underlying observable macroscopic phenomena are above all agencies.

Chemical substances have to be clearly redefined by their intrinsic properties as well as by the dispositions they acquire in acquired in specific circumstances, or the affections they cause on human tissues or senses. This is important to understand the current debates raised by the implementation of a

¹⁶ Pauling, L. “The nature of the theory of resonance”, *Perspectives in Organic Chemistry*, 6-7, quoted in Simões, Gavrolu (2001) p. 66.

¹⁷ Klein ed, 2001.

¹⁸ Bachelard, 1940, p. 60

¹⁹ Hacking, 1983

The chemists' art of synthesis takes advantage of the whole spectrum of qualities in order to put molecules at work, to make them do what humans cannot do with their fingers. In a 2003 conference, Susan Linquist, a biologist from MIT Whitehead Institute, said: "About 10,000 years ago, [humans] began to domesticate plant and animals. Now it's time to domesticate molecules."²⁰ But domesticating molecules is what chemists have been doing for centuries. At the cost of repeated experimental trials, they managed to tame an incredible number of molecules, to get sufficient control over their reactions to be able to use them as agents for performing specific tasks. However domesticated beings never work like man-made tools or machines. They operate according to their own nature, even when they are chemical "creatures". Through a number of more or less spectacular hazards and deplorable accidents, chemists have learned that they are still at the mercy of unexpected circumstances and that reagents do not always behave in a predictable way.

In addition, chemists usually work with huge populations of molecules in their flasks or vats. Unlike nanoscientists who are trying to domesticate isolated molecules, they have no control on individual molecules, although they may know a good deal about the species of molecules, especially when they are their own creations. In fact, the shift in length scale determines radically different relations between men and materials. The slogan of the nano-initiative, “shaping the world atom by atom” expresses the ideal of control and full command that inspires nanotechnology. Individual molecules are supposed to be reliable entities, responding to precise signals. So deep is the contrast between this culture of precision and the more crude style of chemists, that to Eric K Drexler, the champion of nanotechnology, chemical synthesis is an improbable adventure, that he compares to putting together automotive parts in a large box, shaking it with the expectation of finding an assembled car when the shaking is finished.²¹ Such miraculous achievements are nevertheless daily practices in chemical factories. But the car they manufacture is a new whole thing, the parts of which are no longer visible or tangible. In their art of making molecules work for them, chemists are not like Plato’s *демиурго*s, who builds up a world by imposing his own rules and rationality on a passive matter. Rather they are like the ship-pilot at sea, who conducts or guides forces and processes supplied by nature, thus revealing the powers inherent in it.

²¹ Drexler (1995) p. 2