Philosophy *of* Chemistry or Philosophy *with* Chemistry?

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Abstract: Chemistry deserves more philosophical attention not so much to do justice to a long-neglected science or to enhance its cultural prestige, but to undermine a number of taken-for-granted assumptions about scientific rationality and more importantly to diversify our metaphysical views of nature and reality. In brief, this paper does not make the case for a philosophy of chemistry. It rather urges philosophers of science to listen to chemists and discuss what they learn from them. Because over the course of many centuries chemists have developed a special access to nature and a special way of investigating and dealing with material substances, they have confronted a number of epistemological and ontological issues that are worth discussing. Following critical remarks about the disciplinary partition of philosophy, a historical section presents the contributions to philosophy of a few French twentieth-century chemists-turned philosophers to emphasize how they have challenged the dominant philosophical categories. The final section develops one of the lessons that philosophers can learn from chemists: to pay attention to things, to their materiality and activity in order to develop new ontological perspectives.

Keywords: *philosophy of science, disciplines, thing-turn, Gaston Bachelard, Pierre Duhem, Emile Meyerson, Georges Urbain*.

1. Introduction

Philosophy of chemistry has been the poor cousin of the philosophy of science for most of the twentieth century. The standard questions presented in conventional textbooks of philosophy of science – induction, deduction, realism *versus* empiricism – were a long way from the kind of issues an organic chemist has to face on a daily basis in her engagement with reagents at the laboratory bench, with her colleagues and sponsors. Such textbooks provide a caricature of 'armchair philosophy' and have little chance to be of interest for the practitioners of science. They increase the distance between the actual practices of scientific research and the philosophical discourse about science

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that many chemists have already deplored (*e.g.* Berson 2003, Scerri 2009). The inadequacy of conventional philosophy of science demands a profound reform of the curriculum of philosophy of science courses and chemistry has a role to play in this reform.

This paper advocates an integration of chemistry into the philosophy of science, but it does not encourage a disciplinary partition of the field. Chemistry deserves more philosophical attention not so much to do justice to a long-neglected science or to enhance the cultural prestige of chemistry, but to undermine a number of taken-for-granted assumptions about scientific rationality and more importantly to diversify our metaphysical views of nature and reality. Because over the course of many centuries chemists have developed a special access to nature through the laboratory and a special way of investigating and dealing with material substances, they have confronted a number of epistemological and ontological issues that are worth discussing. In brief, this paper does not make the case for a philosophy of chemistry. It rather urges philosophers of science to listen to chemists and pay attention to what they can learn from them. Philosophizing with chemists may help reform the philosophy of science not only by bringing new perspectives on traditional philosophical issues but also because its irreducible materiality determines a host of interesting issues that broaden the repertoire of topics at stake in the philosophy of science.[1]

2. A disciplinary partition of the philosophy of science?

The standard curriculum of philosophy of science is inadequate because it has been shaped according to the philosophical issues of interest in the mid-twentieth century when both analytic and continental philosophers tended to identify science with theoretical physics. It was not uncommon to evaluate the lack of the 'philosophical dignity' of chemistry by its distance from theoretical physics, even implying that chemistry could not have a theoretical framework of its own and had to borrow its theoretical foundations from physics, as Mary-Jo Nye (1993) pointed out. This tacit assumption relied on a sort of blindness concerning the concepts and theories forged by chemists in the eighteenth and nineteenth centuries, prior to the emergence of chemical physics and quantum mechanics. It has prompted strong reactions from a number of scholars who wanted to save chemistry from physics (Scerri & McIntyre 1997). Over the past two decades the philosophy of chemistry has developed as a separate discipline with two specialized journals (*Hyle* and

Foundations of Chemistry), a learned society, and regular international conferences.

Gradually, a disciplinary approach to the philosophy of science has been introduced in a number of textbooks. In addition to the traditional topics (particular topics made generic by twentieth-century theoretical physics) one can find chapters on the philosophies of mathematics, physics, biology, and environmental science. For instance, the table of contents of a recent French textbook (Barberousse *et al*. 2011) is divided into two parts: Section 1 entitled 'General topics': deals with scientific explanation, confirmation and induction, causality, scientific realism, change in science, reduction, and emergence. This section, which presents the traditional body of twentieth century philosophy of science is followed by section 2, which surveys the philosophies of mathematics, of physics, of biology, of medicine, social sciences, economy, cognitive sciences, and linguistics. Such additions are certainly helpful to counterbalance the exclusive attention paid to physics. They suggest that theoretical physics no longer stands as the unique model for developing philosophical views on science. Philosophers of science are ready to acknowledge the evidence of epistemic diversity rather than claiming the unity of science as the heirs of the Vienna Circle did in the mid-twentieth century. Since chemistry is most often omitted from this encyclopaedic survey, it seems more and more legitimate to promote the philosophy of chemistry in order to fill the gap.

However the disciplinary approach generates other distortions. Not only does it tend to over-emphasize some specific features as unique to chemistry, but more importantly, it tends to reify the current disciplinary division of knowledge. It thus overlooks that this division results from a complex and contingent historical process of institutionalization of academic knowledge, which is continuously renegotiated. In other words, promoting the philosophy of chemistry nurtures an essentialist view of disciplines as stable and trans-historic entities with territories of their own (Bensaude Vincent & Stengers, 1996, pp. 3-8). In adopting the academic division of scientific knowledge as a template for the philosophy of science, philosophers get trapped in it and deprived of the capacity to raise alternative and innovative issues.[2]

Without denying that scientists trained as chemists acquire a special way of thinking about nature, a special mind-set, we should not necessarily consider them as disciplinary features. It may be wiser to ascribe their specific epistemology to their research practices rather than to their disciplinary affiliation. Noticeably the notion of 'style' introduced by Alistair Crombie (1994) to emphasize the variety of 'mental ecologies' in scientific research does not refer to disciplinary patterns. The six styles that he identified embrace concepts and theories as well practices, visions, and worldviews that transcend our disciplinary boundaries.[3] When Ian Hacking (2002) revisited Crombie's notion of styles and pointed out a lacuna in his typology he equally avoided any reference to specific disciplines. He added a 'laboratory style' taking into account experimentations characterized by the production of phenomena through apparatus and manipulations. The specificity of this additional style is clearly defined by the site of knowledge: the laboratory as a protected and confined space where natural phenomena are investigated through operations. Although the laboratory was invented by medieval and early modern chemists who greatly contributed to the advancement of experimental philosophy as a number of historians of chemistry have argued (Holmes 1993, Newman & Principe 2003, Newman 2006), it is not the exclusive property of chemists. While laboratory practices have shaped a chemists' style, it would nevertheless be irrelevant to claim that all experimental practices are indebted to chemistry or that chemists have an intellectual property right over them. Therefore instead of trying to outline the philosophical identity of chemistry, it is more interesting to look at what philosophers have learnt and could learn from chemical practices.

3. Exemplary interactions between chemistry and philosophy

In the early twentieth century French philosophy was often characterized by its focus on positive science (Bergson 1915, p. 31; Lavelle 1942, p. 242). A tradition of philosophy of science emerged through close interactions between scientists and philosophers and strong links between philosophy and history of science (Brenner 2003). As a matter of fact, a number of chemists-turned philosophers discussed the chemical approach to atomism in such a way that they blurred the clear boundary between realism and positivism, which dominated the philosophical debates of the time. It is worth revisiting their works because they can offer examples for broadening the repertoire of philosophical issues through a dialogue between chemists and philosophers.

Pierre Duhem, a physical chemist who aimed at unifying chemistry and physics, developed an interest in epistemology and history of science early in his career. While he was shaping his holistic thesis (known as the Duhem-Quine thesis) he authored a number or articles bundled together in a volume *Le mixte et la combinaison chimique* (Duhem 1902). He advocated an Aristotelian philosophy of matter against atomism. Without denying that atomic formulae were useful for prediction, he rejected as naïve the description of chemical combinations in terms of a juxtaposition of persistent atoms bound by hooks and spikes. He criticized the realist interpretation of atomism and advocated a view of theory as a tools for classifying rather than explaining phenomena. Because of such criticism, Duhem has been quickly labelled as a supporter of the positivist camp against the realist one by most philosophers of science[4]. In this case the dilemma of realism/positivism simply obliterates Duhem's philosophical concern with the dynamics of chemical combinations. Dissatisfied with the mechanistic interpretation of atoms binding together, Duhem was trying to draw the philosophical attention toward the kind of process that happens in chemical reactions (Vauthelin 2007).

In 1921, Georges Urbain, a French chemist who gained an international reputation for his experimental work on rare earths, published his philosophical reflections on chemistry (Urbain 1921). The title – *Les disciplines d'une science, la chimie* – suggests that this is an ideal place to grasp what the philosophy of chemistry meant for working chemists. A quick glimpse of the book suggests that Urbain was a staunch advocate of positivism: he emphasized the role of sensory experience; he claimed that the main function of theories was to organize and classify data, that the goal of science was prediction and action, that atoms are fictions and above all, he repeatedly quoted Auguste Comte. Any reader with a minimum background in the philosophy of science would conclude that Urbain is anti-realist qua positivist. Some even argued that French chemists campaigned against atomism (equated with realism) because they were under the influence of Comtean positivism, which caused the delay of French chemistry in the 1930s (Charpentier-Morizé 1997).[5] As a matter of fact, Urbain simply ignored the dilemma and desperately tried to reconcile the rival doctrines of atomism and energetism. He was at the same time a positivist and a realist. In particular he advocated a strong realism about chemical substances when he wrote: "This remarkable consensus [about scientific facts] generates a climate of trust between scientists […] a robust faith. There may not be one single chemist who has doubts about the reality of barium sulphide" (Urbain 1921, p. 18).

Urbain even became a major ally of Emile Meyerson, another chemist-philosopher who is known for his attacks against positivism and for his robust realism (Meyerson 2009, pp. 887-990). Meyerson often quoted Urbain's remark (above) to support his own claims that all scientists spontaneously believe in the reality of their objects and that there is no science without ontology (Meyerson 1921, p. 560). Did he misunderstand Urbain? Was he totally blind to his claims that atoms were just 'pieces of fine arts'? To be sure, Meyerson slightly distorted and radicalized Urbain's remark about the chemists' faith in the reality of barium sulphide. However, he shared his feelings as a laboratory chemist about the origin of the 'robust faith'. It derives from the intimate knowledge that laboratory scientists acquire through shared habitus while working together at the bench. Meyerson often mentioned that he was impressed by the sort of 'instinct' that Robert Bunsen –

his former supervisor in Heidelberg – had acquired through years of laboratory practice. “He gave the impression that he saw ‘from the inside’ as people used to say around him, that he guessed thanks to a superior instinct the essence of the real” (Meyerson 1931, pp. 494-95). Bunsen was guided by rules and methods only transmitted through practice, which allowed him to instantly find explanations and remedies for anomalies. Meyerson was therefore quick to understand that Urbain’s major philosophical concern in this volume was to disentangle the conditions in which chemists reach agreements on matters of fact, in other terms how they form what Ludwig Fleck called a *Denk-Kollektiv*.

The term ‘*disciplines*’ (with plural) in the title of Urbain’s book refers to the tacit norms, values, and affects that rule the chemists’ reasoning and behavior, and not to the subject matter taught at school. Such disciplines, he claimed, are acquired through laboratory practice. In other words, Urbain described what today’s epistemologists, such as Lorraine Daston, would call the ‘moral economy’ of chemists. “Much of the stability and integrity of a moral economy derives from its ties to activities, such as precision, measurement or collaborative empiricism, which anchor and entrench but do not determine it” (Daston 1995, p. 4). The question discussed in Urbain’s book is: To what extent does the practice of a certain research field determine theoretical choices? Meyerson’s and Urbain’s major concern was to contribute to the theory of knowledge, to describe how scientists really work, how they reach a consensus, their ways of thinking, their beliefs and assumptions. Meyerson himself advocated neither realism nor idealism, but from his own experience as a chemist and from his investigations in the history of science he had acquired the conviction that all scientists made ontological assumptions.

How did Meyerson approach chemistry? He admitted that the philosophy of science should not exclusively be centered on mathematics and philosophy. Although he never tried to outline the singularity of chemistry among other sciences, Meyerson stressed that chemists, in stark contrast to physicists, are mainly interested in the qualities of matter and accordingly strongly reject the reduction of secondary qualities to primary ones. He argued that the existence of irreducible qualities, of material properties that cannot be reduced to geometrical figures, is one of the ‘irrationals’ brought about by chemistry. For Meyerson the identification of chemical atoms with electrical entities did not dissolve the irrationality. The electrical units (electrons, ions, protons) are as ‘occult’ and as obscure as the billiard balls of classical mechanics. And he firmly concluded a discussion with the physical chemist Anfré Job saying: “Scientists or philosophers, we all know that reality is inaccessible. We all know that whatever we can do, we will never eliminate the irrational from the image that we create of it.” (Job 1912)

Meyerson resolutely discarded any possible reduction of chemistry to physics and identified qualities as the 'irrational' proper to chemistry. (Meyerson 1931, pp. 501-3) The second 'irrational' is the existence of multiple chemical elements. "The true element, that which has to remain indecomposable, is by definition an irrational, something that reason is condemned to acknowledge as an eternally recalcitrant given." (Meyerson 1921, pp. 170-1) Thus Meyerson described chemistry as torn between two tendencies: experimental results impose an increasing diversity of chemical elements while the *a priori* tendency of our intellect to identify everything denies or tries to reduce the plurality of chemical elements. Finally the very existence of chemistry as an independent science proves that rational hopes of the total reduction of diversity are chimerical. Chemistry epitomizes the death of the rational myth of complete deduction of nature from a few principles.

Despite the importance of chemistry in Meyerson's works, he never attempted to distinguish the philosophy of chemistry from that of physics or mathematics. On the contrary, chemistry provided him with a wealth of examples to confirm his general theory that sciences advance through the conflict between two antagonistic movements: the rational tendency to 'identification' and the evidence of 'irrationals' brought about by the contact with the real. Material diversity in space is equivalent to Carnot's principle in time. It is a radical obstacle to our effort to 'identify' everything, reduce diversity and deduce the real from the rational.

Gaston Bachelard, who was a physics and chemistry teacher when he took a PhD in philosophy, revisited Meyerson's issue of an oscillation between pluralism, on the one hand, and the reduction of plurality, on the other, in an essay dedicated to chemistry (Bachelard 1932). His conclusions deeply differed from Meyerson's views. While Meyerson argued that the antagonism between the two tendencies – unity and plurality – was irreducible and constitutive of scientific activity, Bachelard described a progress in the subordination of the multiplicity of substances to unity in three stages that ended up in a celebration of harmony. He thus initially presented chemistry as an instantiation of the increasing power of mathematics (in this case arithmetic) over physical sciences. But gradually he changed his view of chemistry. In his later works, he emphasized the distinctive features of chemistry and its unique contribution to philosophy. In *La philosophie du non*, he coined the term 'metachemistry' as an alternative to metaphysics. In metaphysics, matter is a generic entity. This abstraction results from a quick glance at the outside world by a pre-existing subject. It is instantiated in Descartes' meditation on a piece of wax, the counterpart of his substantialist view of the *cogito*.

> Metaphysics could have only one possible notion of substance because the elementary conception of physical phenomena was content to study a geometrical solid characterized by general properties. Metachemistry will benefit by

> the chemical knowledge of various substantial activities. It will also benefit from the fact that true chemical substances are the products of technique rather than bodies found in reality. This is as much as to show that the real in chemistry is a realization [Bachelard 1940, p. 45].

By contrast, 'metachemistry' pays attention to the plurality of materials and, more importantly, takes into account all the technical work necessary for chemical substances to exist: they are real because they have been 'realized', *i.e.* synthesized or purified. The 'realization' of chemical substances by the 'apparatus of knowing' is a process of mutual instruction between objects and subjects. Bachelard also characterized a 'chemical rationalism' based on a 'dialectic notion of substance'. His notion of dialectics was somewhat loose. Substance is a dialectic notion because it is the result of a dialogue between theory and experiment, between human intervention and nature, as well as a dialogue between scientists because chemical activity has to be a collective enterprise. As Alfred Nordmann has argued, in order to reform metaphysics and philosophy of science Bachelard did not content himself to emphasize the specificity of chemistry as opposed to physics. "Instead of chemistry aspiring to hold its own place in the pantheon of the sciences, the notion of metachemistry refers to chemistry as a technology for bringing forth new things" (Nordmann 2009, p. 342). Bachelard turned his attention to the materiality of chemical practices, and emphasized their concern with things.

To sum up this Section, two possible lessons can be retained from this quick survey of a number of chemists-philosophers. First, pay attention to the philosophical concerns expressed by working chemists, try to identify what matters for them rather than searching for answers to standard philosophical issues. Second, the matters of concern raised by the actual practices of chemists in their specific research field are not necessarily specific to chemistry. It would be naïve to think that following chemists in their practices gives access to the conceptual foundations of chemistry, thus delivering the essentials of a philosophy of chemistry (again the quest for the essence of chemistry!). But this attitude may open up new avenues of research in philosophy.

4. Conclusion: Toward a thing turn in philosophy

Among the benefits of an intensified conversation between philosophers and chemists, one is the heuristic power of reflections on material things. Many chemists are famous for their art of making up thoughtful short stories on the basis of material substances. Their strong attachment to individual substances is instantiated in Primo Levi's masterpiece *The Periodic Table* (Levi

1975), as well as in Roald Hoffmann's collection of papers in *The Same and not the Same* (Hoffmann 1995) or Pierre Laszlo's stories based on his lifelong research on clay solids (Laszlo 2000 and 2004). Philosophers can first learn from them how much materiality matters. Indeed, the 'practical turn' in science studies has already encouraged philosophers of science to pay more attention to the material aspects of science, to consider instrumental practices, material constraints, and experimental systems (*e.g.* Rheinberger 1997, Baird 2004). And the vitality of the Society for Philosophy of Science in Practice, created in the 2000s, suggests that the practical turn has been a true success. However, by listening to chemists, we can do a next move, a 'thing turn'.

By 'thing turn' I mean that things, the most familiar and ordinary things that we encounter in daily life, provide a unique angle for raising and discussing philosophical issues.[6] The French nineteenth-century educational system included a subject matter for primary school labeled '*leçons de choses*'. Although these 'lessons from things' were primarily dedicated to natural history, it is possible to divert this phrase to emphasize that chemistry is a cornucopia of common substances apt to catalyze complex philosophical reflections.

Sugar and common salt instantiate this empirical approach to philosophy. Sugar was Duhem's choice to introduce his views on mixture and chemical combination.

> Throw a little sugar into a glass of water. After a short time, the solid white crystalline body, which constitutes the sugar has disappeared. The glass contains no more than a homogeneous liquid, transparent like water, but with a different taste. What is this liquid? The vulgar call it sugared water. The chemist says that it is a solution of sugar in water. These two descriptions correspond to two essentially distinct opinions. [Duhem 1902, pp. 11-15]

With this clear and simple example, Duhem tried to concern his fellow scientists with an ancient and outmoded notion of 'mixt'. In his refutation of atomism, Aristotle introduced a distinction between the 'apparent mixture' – for instance of grains of wheat and barley – which is a mere juxtaposition of components, and the 'true mixt', which is the generation of a new substance out of the components (*De gen. et cor*. I, 10). The distinction was revived by Stahlian chemists in the eighteenth century in order to confine the mechanical explanations of chemical combinations: they drew a clear boundary between 'aggregation' – a mechanical union – and 'mixtion' – the union of heterogeneous components resulting in a homogeneous substance (Venel 1763, Bensaude Vincent 2009). However chemists have dropped the ancient term 'mixt' by the end of the eighteenth-century, and the reform of chemical language simply discarded the issue in assuming that compounds were formed by the addition of two components. Undoubtedly in 1902 the Aristotelian notion looked completely obsolete in the era of molecular models! In confronting the 'vulgar' and the 'expert' answers to the question 'what is this liquid?' Duhem undermined the evidence of the established molecular interpretation of dissolutions: *i.e.* the sugared water is not really homogeneous at the microscopic level. The homogeneity of sugared water is an illusion of our senses: the smallest parts do not possess the same properties as the whole. The next chapters clearly show that Duhem's purpose in reviving the Aristotelian notion of true mixt was to make the case for an alternative thermodynamic explanation of what happens in the process of chemical combination in terms of potentials. Duhem attempted to solve this vexing puzzle by substituting the Aristotelian notion of potential (*dunamis*) for the thermodynamic potential, which provides a mathematical description of states without investigating what happens to the components in the course of chemical change.

Common salt is another example of an ordinary thing that has used to prompt philosophical reflections since the nineteenth century to nowadays (*e.g.* Earley 1998, 2005). The question 'How the union of a soft metal like sodium and a greenish gas like chlorine can give a colourless salt?' is a philosophical *topos*. For most chemists this is a very naïve or purely rhetorical question which suggests that philosophers ought to be careful and learn at least elementary chemistry. 'In truth', sodium chloride is not the product of metallic sodium and chlorine gas. Rather it is the product of sodium hydroxide combining with hydrochloric acid, and one should pay attention to the various oxidation states of an element. However philosophers rightly insist on the puzzle of sodium chloride, and chemists in turn may have to listen carefully to philosophers. Whatever the accounts chemists use to get rid of the puzzle – in molecular, thermodynamic or quantum terms – this philosophical cliché proved fruitful for clearly stating and discussing extremely complex and interrelated philosophical issues raised by chemical combinations such as causality, emergence, and the ontological status of chemical entities.

For instance, Meyerson found in sodium chloride a robust argument to question the chemists' fetishist attachment to the principle of conservation of matter: "When I realize that a soft metal and a yellowish gas, as in the reaction of chlorine on sodium, give birth to colorless crystals, how can I claim that what remains is more important than what has changed?" (Meyerson 1931, §54). He even claimed that the chemical equation $Na+Cl=NaCl$ is strictly speaking absurd. He compared it with the famous statement 'Bororos are araras' (*i.e.* the Bororos people are parrots), which anthropologist Lucien Lévy-Bruhl used for arguing that 'primitive mentalities' violate the principle of non-contradiction, the very foundation of our logic. Chemists cannot formally equate the ingredients and the products of a chemical reaction. Thus chemical equations, which epitomize the quantitative and modern chemistry initiated by Lavoisier, are typical of a totemic way of thinking, in Meyerson's view. He conceded that van 't Hoff's decision to replace the sign '=' by an arrow was a true improvement, but he doubted that it had changed the chemists' conviction that they were dealing with equations. (Meyerson 1931, p. 414) Chemical equations express our intellect's chimerical and absurd expectation that if we could have a complete knowledge of the world, antecedents and consequences would be recognized as identical, that the real is entirely rational.

Although the concept of emergence immediately draws the attention to life sciences and the issue of the vital force, there is a form of emergence in chemistry because the whole differs from the sum of its parts (Llored 2013). Therefore the theoreticians of emergence frequently looked at chemical combinations. British philosopher Charlie Dunbar Broad used sodium chloride to formulate his theory of emergence:

> I will merely remark that, so far as we know at present, the characteristic behaviour of Common Salt cannot be deduced from the most complete knowledge of the properties of Sodium in isolation; or of Chlorine in isolation; or of other compounds of Sodium, such as Sodium Sulphate, and of other compounds of Chlorine, such as Silver Chloride. [Broad 1925, p. 57; quoted from Llored 2013, p. 258]

Emergence in the case of chemistry does not convey the presence of a mysterious vital force. It rather connotes doubts on chemical explanations. In spite of the conservation of weight, the properties of the whole cannot be deduced from those of the parts and they cannot be predicted before the instantiation of the chemical combination. In *Problems of Life and Mind*, Victorian philosopher George Henry Lewes (1875, 51) raised the 'rhetorical question':

> In this pinch of table salt there is no appearance of the soft metal sodium, or the pungent gas chlorine, which the mental eye of the chemist sees there, and which all men of science would declare to be really there, supporting their assertion by dragging out both metal and gas, and presenting them to Sense. I, on the contrary, maintain that neither metal nor gas *is* there; and my assertion is supported by the fact that so long as the salt remains *salt* no trace of *gas* or *metal* can be perceived. To prove his assertion that these elements are really present, underlying the appearances, the chemist has to completely alter the whole group of relations, and for that group substitute a different group, *then*, indeed, metal and gas will appear [Lewes 1875 p. 51; quoted from Llored 2013, p. 208].

Lewes pointed to a contradiction inherent in modern chemistry: sodium and chorine are here and not here in table salt. They are conserved since they can be retrieved (principle of conservation) although their properties disappear. The example points to the deficiency of the concept of elementary substance – what remains underneath and unchanged. This inadequacy calls for thorough investigations of the modes of existence of chemicals, which are by no means self-evident.

To be sure sodium chloride may not be an ideal exemplar for raising ontological issues. The substance that chemists prepare in a flask by reacting chlorine on sodium is not exactly the one we put on boiled eggs.[7] Table salt is usually extracted from seawater rather than synthesized. Its mode of existence as an ordinary thing, and an important actor in human history is quite different from its chemical mode of existence as sodium chloride. A thing turn in philosophy requires that chemicals be envisioned in their various settings rather than just as laboratory products.

Moreover, chemical substances are not samples of a Cartesian passive matter. They are active and reactive individuals whose behavior is partly determined by the neighboring substances. Therefore they require a relational ontology. Bachelard already stated that "intermaterialism is a notion grounded in the brute experience of chemical reactions" (Bachelard 1953, p. 29). This intuition can be further explored with many chemicals. The properties of a sodium atom change according to neighbor atoms or molecules. The 'relatedness' of atoms in a molecule and of H_2O molecules in a glass of water calls for a relational ontology that could be inspired by the eighteenth-century '*tables de rapports*' and instantiated in many contemporary cases (*e.g.* s-tetrazine in Llored 2013). Examples of cooperative behaviors especially in supra-molecular chemistry could also help revise the old essentialist ontology. The dispositions of chemical substances are 'activated' by the neighbors or sometimes created by instruments. In a sense the apparatus makes actual what was potential in natural things. This phenomenon requires a new category, *affordance*. Rom Harré introduced this notion of affordance precisely with the example of metallic sodium. The question whether metallic sodium existed before Humphrey Davy invented electrolysis is illegitimate, since it is nature and the electrolytic apparatus which afford metallic sodium (Harré 2003). There is no fixed essence of metallic sodium. Affordances manifest both the dispositions of atoms and the world/apparatus complex. This category – a hybrid of nature and artifact, of objective properties and human purposes – is especially relevant for characterizing the ontological status of chemical entities. Therefore they are an ideal field for exploring the hypothesis that things have multiple modes of existence at the same time and to conduct an inquiry into modes of existence (Latour 2012). As Bachelard argued, all pure and simple substances are 'facticious'. Once analyzed, purified, and characterized, chemicals are hybrid products of nature, instruments, and operations. Since they require a lot of technicians and instrument-makers, in addition to specific experts and bureaus to set up the standards of purity, and inspectors to guarantee the conformity to those standards, "hydrogen and oxygen are, in many respects, so to speak, social gases, highly civilized gases"

(Bachelard 1953, p. 31). They have a variety of modes of existence: natural, artificial, and cultural. Given the importance of facticity in chemistry, Bachelard suggested that chemistry is a human science rather than a natural science. "Nature wanted to really perform chemistry, therefore she invented the chemist" (*ibid*., p. 33).

Carbon provides a good case to instantiate the multiple modes of existence (Loeve & Bensaude Vincent, forthcoming). It has so many identities (diamond, graphite, charcoal, fullerenes, nanotubes, graphene,…) that it challenges the relevance of the abstract metaphysical concept of a substrate underlying all these phenomenological appearances. Thanks to its bonding capacities it displays a wide range of dispositions and affordances. Furthermore the definition of carbon as an element in the periodic table is too narrow to contain all its facets and roles in human history, just as the definition of water as H_2O has been questioned by Hasok Chang (2012). Carbon also exists as a key component of living beings in the backbone of DNA, and the cycle of carbon dioxide connects the plant, animal, and mineral realms of nature. It is also a driver of technology, since coal and oil were prominent actors in the industrial revolution. It even acquired a political mode of existence when coal inspired social movements that oil economy repressed, as Timothy Mitchell (2011) argues. Furthermore, nowadays as human societies realize the impacts of their carbon-based technologies and try to fix the damages to the planet, carbon has received a new mode of existence in the market economy as a general equivalent in carbon trading. Carbon and presumably many other similar things help promote a new anthropology that challenges the disciplinary fragmentation.[8]

Chemical molecules do not come into being out of necessity. They exist as composites of nature and society, of theoretical potentials, social or economic pressures, as well as environmental requirements. Chemists using fashionable methods of rational design or combinatorial chemistry aimed at dispensing with the painstaking trial-and-error methods often talk of 'chemical space'. This metaphorical notion, forged by analogy to astronomical space, results from a joint effort of an academic journal (*Nature*) and a pharmaceutical company (Aventis) to foster the production of new molecules of interest.[9] Chemical space, as they understand it, is a virtual reality made of an incredible number (about 10^{60}) of possible organic molecules. Just as only a small portion of the astronomical space populated by billions of celestial bodies has been explored, only a small region of chemical space can be explored. "A key question is how we should direct our efforts towards regions of chemical space that are most likely to contain molecules with useful biological activity" (Anonymous 2004). In the discourse of chemical companies it seems that chemical molecules come into existence as objects of desire and design. However this may be an illusion. The chemical space should not be conceived of as a Newtonian space where molecules would stand as discrete and isolated entities with permanent properties waiting to be actualized and used. Their virtual properties are determined by their associations with other molecules or with the environment and also by the process of actualization itself (*in silico*, *in vitro*, or *in vivo*). As Andrew Barry rightly remarked: "chemical space is a relational space, the coordinates of which are governed by the particular medical chemical process under investigation. Two different molecules which exist in close proximity to each other in relation to one specific process, for example, may be distant from each other when viewed in relation to a different process" (Barry 2005, p. 62). Therefore chemical molecules rather exist as events in a world already furbished with crowds of interacting beings.

The thing turn inspired by chemistry has the potential to renew the issues and concepts not only in epistemology and ontology but also in ethics. Indeed, with the emergence of synthetic chemistry in the nineteenth-century chemists developed a kind of hubris. In particular, Marcellin Berthelot's famous statement 'chemistry creates its objects' has encouraged illusions of power over matter by presenting synthesis as a gradual and systematic process seemingly effortless and under control. Nowadays, the methods for modeling molecules and deducing their properties from theories or computations bring about similar ambitions. Rational design and the fabrication of materials by design have revived the chemists' great Promethean ambitions. Considering the intrinsic dispositions of chemicals and their affordances, however, it seems unlikely that chemists can get rid of all empirical, trial-and error methods (Simon 2012). A better understanding of the ontology of chemicals may be a lesson in humility. Chemists skilled in the art of synthesis having an intimate knowledge of chemicals are more inclined than other scientists to acknowledge the risks inherent in the chemical substances, in their dispositions and responses to the environment and the circumstances. They know the tricks needed to negotiate with their dispositions and affordances.[10] They consequently tend to downplay all the hype and hubris surrounding the power of synthesis (Jansen & Schön 2005). Furthermore, for ethical and environmental reasons not all the 10^{60} molecules that populate chemical space should be allowed to come into existence. Many of them are too toxic or simply too unnatural to share the world with us. Maybe some of them do not want to exist! (Marris 2007)

To conclude, this paper is a plea for intensifying the dialogue between philosophers and chemists. Many philosophers and chemists have promoted the philosophy of chemistry over the past two decades. It is therefore less relevant to complain about the prejudices concerning chemistry and to make the case for its philosophical dignity. Moreover, it does not make much sense to defend disciplinary identities as most chemists work today in trans-disciplinary fields such as materials science, nanotechnology, environmental science, or bioengineering. The disciplinary identity of chemistry is not the major concern of every single professional chemist. Listening to them and trying to disentangle their matters of concern with a view to formulate and discuss their philosophical assumptions seems to me a much more promising attitude.

This paper had no ambition to review all the philosophical issues arising from chemistry. In particular it does not consider the many revisions that chemistry imposes on traditional philosophical issues such as the role and function of theories, and of simulation, or the divide between the natural and the artificial. It rather focuses only on the engagement of chemists with the material and individual entities that they bring into the world. This care for things may not be the specific feature of chemistry, but it is one of the lessons that philosophers may want to retain and discuss with chemists as it certainly has the potential to renew their stock of ontological concepts.

Notes

1 This paper develops some of the views outlined in the course of a brief discussion about *Chemistry the Impure Science* between Bernadette Bensaude Vincent, Jonathan Simon, Hasok Chang, and Alfred Nordmann in *Metascience*, 19 (3) 2010, pp. 373-383.

2 Michel Serres did similar criticisms of the division of the history of science in history of mathematics, of astronomy, of physics…(Serres 1977, pp. 18-19).

3 The six different styles distinguished by Crombie were: (1) postulation, (2) experimental argument, (3) hypothetical modeling, (4) taxonomy logic, (5) probabilistic and statistical analysis, and (6) historical derivation.

4 A noticeable exception was Emile Meyerson, himself a staunch realist. He refused to view Duhem as a positivist: "He knows too much the way of thinking of a savant to fully adopt such claims and he frequently uses unorthodox expressions. I may not be a good judge in this respect. I took a lot from him and it is possible that while reading him I lent him some views." (letter to André Lalande, August 1929, in Meyerson 2009, p. 296).

5 On the misunderstanding of atomic debates in France see B. Bensaude Vincent (1999).

6 Dutch philosopher Peter Paul Verbeek makes the case for a similar "thingly turn" in his approach to technological design (Verbeek 2005, p. 3).

7 As suggested by a video from UC Berkeley https://www.youtube.com/watch?v=d2geiGKFveE.

8 A similar research field is explored by ethnographers. See Henare *et al*. 2007.

9 Note that the concept of chemical space, as a mathematically defined topological space that takes the relational ontology seriously, was introduced in the philosophy of chemistry in the 1990s (Schummer 1996, pp. 215-223).

[10] Skilled synthetic chemists are not however infallible because chemicals remain essentially unpredictable. I am grateful to one anonymous referee who mentioned the case of the two co-workers of the late Canadian chemist Saul Winstein who died from exposure to two novel compounds they had synthesized: there was no way to predict their lethality.

References

Anonymous: 2004, 'Horizon Symposium. Charting chemical space: Finding new tools to explore biology', *Insight Nature*, **432**, 823.

Bachelard, G.: 1932 [1973], Le pluralisme cohérent de la chimie moderne, Paris: Vrin.

Bachelard, G.: 1934 [1958], *Le nouvel esprit scientifique*, Paris: Vrin.

Bachelard, G.: 1940, *La Philosophie du non. Essai d'une philosophie du nouvel esprit scientifique*, Paris: PUF [re-edition Paris: PUF, 1988. Engl. trans. *The Philosophy of No. A Philosophy of the New Scientific Mind.* New York: Orion, 1968].

Bachelard, G.: 1953, *Le matérialisme rationnel*, Paris: PUF.

Baird, D.: 2004, *Thing Knowledge: A Philosophy of Scientific Instruments*, Berkeley: University of California Press.

Barberousse, A.; Bonnay, D. & Cozic, M.: 2011, *Précis de philosophie des sciences,* Paris: Vuibert.

Barry A.: 2005, 'Pharmaceutical matters: the invention of informed materials', *Theory, Culture and Society,* **22**(1), 51-69.

Bensaude-Vincent, B.; Stengers, I.: 1996, *A History of Chemistry*, Cambridge, MA: Harvard University Press.

Bensaude-Vincent, B.: 1999, 'Atomism and Positivism: A Legend about French Chemistry', *Annals of Science*, **56**, 81-94.

Bensaude-Vincent, B. : 2009, 'Le mixte ou l'affirmation d'une identité de la chimie', *Corpus, Revue de philosophie*, **56**, 117-142.

Bergson, H.: 1915, 'La philosophie', in: *La science française à l'exposition de San Francisco*, vol. 1, Paris: Ministère de l'instruction publique.

Berson J.A.: 2003, *Chemical Discovery and the Logicians' Program. A Problematic Pairing*, Weinheim: Wiley-VCH.

Brenner, A.: 2003, *Les origines françaises de la philosophie des sciences*, Paris: PUF.

Chang, H.: 2012, *Is Water H_2O? Evidence, Realism and Pluralism*, Dordrecht: Springer.

Charpentier-Morizé, M.: 1997, *Perrin, savant et homme politique*, Paris: Belin.

Crombie, A.: 1994, *Styles of Scientific Thinking in the European Tradition*, London: Gerald Duckworth.

Daston, L.: 1995, 'The moral economy of science', *Osiris*, **10**, 3-24.

Duhem, P.: 1892, 'Notation atomique et hypothèses atomistiques', *Revue des questions scientifiques*, **31**, 391-454.

Duhem, P.: 1902, *Le mixte et la combinaison chimique*. [Quoted from the second ed. Paris, Fayard, Corpus des œuvres philosophiques en langue française, 1985. Engl. trans. by P. Needham: *Mixture and Chemical Combination and Related Essays*, Dordrecht: Kluwer, 2002.]

Earley, J.E.: 1998, 'Mode of Chemical Becoming', *Hyle: International Journal for Philosophy of Chemistry*, **4**(2), 105-115.

Earley, J. E.: 2005, 'Why there is no salt in the sea', *Foundations of Chemistry*, **7**, 185-102.

Hacking, I.: 2002, ''Style' for historians and philosophers', in: Hacking, I. (ed.), *Historical Ontology,* Cambridge: Harvard University Press, pp. 178-199.

Harré, R.: 2003, 'The materiality of instruments in a metaphysics for experiments', in: H. Radder (ed.), *The Philosophy of Experimentation*, Pittsburgh: Pittsburgh University Press, pp. 19-38.

Henare, A.; Holbraad, M. & Wastell, S. (eds): 2007, *Thinking Through Things: Theorizing Artifacts Ethnographically,* London: Routledge.

Hoffmann, R.: 1995, *The Same and not the Same*, New York: Columbia University Press.

Holmes, F. L.: 1993, 'La chimica nell'eta dei Lumi', in: Abbri, F. & Mazzolini, G. (eds.), *Storia delle scienze Natura e Vita*, vol. 3, *Dall'Antichita all'illuminismo*, Torino: Giulio Einaudi, pp. 478-525.

Jansen, M & Schön, J.C.: 2006, 'Design in Chemical Synthesis – An Illusion?', *Angewandte Chemie International*, **45**, 3406 – 3412.

Job, A.: 1912, 'Le progrès des théories chimiques', *Bulletin de la Société française de philosophie*, no. 2, 47-62.

Laszlo, P.: 2000, *Terre & eau, air & feu*, Paris: Le Pommier.

Laszlo, P.: 2004, *Le phénix et la salamandre. Histoires de sciences*, Paris: Le Pommier.

Latour, B.: 2012, *Enquête sur les modes d'existence. Une anthropologie des modernes*, Paris: éditions la découverte. [Engl. trans.: *An Inquiry into Modes of Existence*, Cambridge: Harvard University Press, 2013.]

Lavelle, L.: 1942, *La philosophie française entre les deux guerres*, Paris, Aubier.

Levi, P.: 1975, *Il sistema periodico* [Engl. trans.: *The Periodic Table*, New York: Schorcken, 1984.]

Lewes, G.H.: 1874-75, *Problems of Life and Mind,* London: Turner.

Loeve, S. & Bensaude-Vincent, B.: forthcoming, 'The multiple signatures of carbon. Ontography': in B. Bensaude-Vincent *et al*. (eds.), *Research Objects in their Technological Setting,* London: Pickering & Chatto.

Llored, J.P.: 2013, *Chimie, chimie quantique et concept d'émergence. Étude d'une mise en relation*, Palaiseau: Thèse de l'école polytechnique.

Marris, E.: 2007, 'Teetering on the edge', *Nature*, **447**, 431.

Meyerson, E.: 1921, *De l'explication dans les sciences*, Paris: Payot. [Quoted from the new edition Paris: Fayard, 1995. Engl. Trans. by M-A. and D.A. Sipfle: *Explanation in the Sciences,* Dordrecht: Kluwer, 1991.]

Meyerson, E.: 1931, *Le Cheminement de la pensée*, Paris: Payot.

Meyerson, E.: 2009, *Lettres françaises*, edited by B. Bensaude-Vincent and E. Telkes-Klein, Paris: éditions CNRS.

Mitchell, T.: 2011, *Carbon Democracy. Political Power in the Age of Oil*, London, New York: Verso.

Newman, W.R.; Principe L.: 2003, *Alchemy tried in the Fire*, Chicago: The University of Chicago Press.

Newman, W.R.: 2006, *Atoms and Alchemy, Chemistry and the Experimental Origins of the Scientific Revolution*, Chicago: University of Chicago Press.

Nordmann, A.: 2009, 'From metaphysics to metachemistry', in: D. Baird, E. Scerri & L. McIntyre (eds.), *Philosophy of Chemistry*, Dordrecht: Springer, pp. 342-362.

Nye, M.-J.: 1993, *From Chemical Philosophy to Theoretical Chemistry*: *Dynamics of Matter and Dynamics of Disciplines, 1800-1950,* Berkeley: University of California Press.

Rheinberger, H.J.: 1997, *Toward a History of Epistemic Things. Synthesizing Proteins in a Test-Tube*, Stanford: Stanford University Press.

Schummer J.: 1996, *Realismus und Chemie: Philosophische Untersuchungen der Wissenschaft von den Stoffen*, Würzburg: Königshausen & Neumann.
Scerri, E.: 2009, 'Chemistry goes abstract', *Nature Chemistry*, **1**, 679-680.
Scerri, E. & McIntyre, L.: 1997, 'The Case for the Philosophy of Chemistry', *Synthese*, **111**(3), 213-232.
Serres, M.:1977, *Hermès IV. La distribution*, 1977, Paris: éditions de minuit.
Simon, J.: 2012, 'Chemistry and Pharmacy: A Philosophical inquiry into an evolving relationship', in: D.M. Gabbay, P. Thagard & J. Woods (eds.), *Philosophy of Chemistry*, San Diego: North Holland, p. 519-530.
Urbain, G.: 1921, *Les disciplines d'une science, la chimie*, Paris: Librairie Doin.
Vauthelin, P.M.: 2007, *Aux origines de La théorie physique: l'énergétique de Pierre Duhem (1885-1911),* Nanterre, Thèse de l'Université Paris Ouest.
Venel, G.F.: 1763, 'mixte & mixtion', in: Diderot & D'Alembert (eds.), *Encyclopédie*, vol. 10, p. 588.
Verbeek, P.P.: 2005, *What Things Do, Philosophical Reflections on Technology, Agency and Design*, Philadelphia, Pennsylvania State University Press.

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