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Historical Article

For a Dialogue Between the Teaching of Chemistry and the History and Philosophy of Chemistry: the Case of the Concept of 'Chemical Element'

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Abstract. The concept of 'element' is one of the most important concepts in the chemical sciences. It plays a key role to explain the chemical reactions and the basis of the periodic table. It is also central to the modern philosophy of chemistry because of its role in discussions about the nature of the periodic system and natural classes. In the field of chemistry teaching it is a paradigmatic case of alternative conceptions. In general, two definitions of 'chemical element' coexist. The first, due to Lavoisier, conceptualizes an 'element' in a macroscopic ontology and the second, usually considered the 'modern' definition, conceptualizes an element in an ontology of particle. Some authors state that it is time to consider the former conceptualization as merely 'historical' and focus teaching on the basis of the most recent definition. The present paper aims to address this problem from a pluralist perspective by highlighting the pedagogical relevance of incorporating historical-philosophical analyses in the explanation of scientific concepts.

Keywords: chemical element, Lavoisier, Mendeleev, Paneth, history and philosophy of chemistry.

INTRODUCTION

The concept of 'element' is one of the main categories of the chemical world. It plays a central role both in chemical reactions and in the periodic table, and it is of the utmost importance for the philosophy of chemistry because of its role in discussions about the nature of the periodic system and the problem of natural kinds. With the revival of the philosophy of chemistry in the middle of the 1990s, some chemists, philosophers of chemistry, and historians of chemistry sought to clarify this concept. But at present the disagreements are deep: while there is a broad consensus about the *extension* of the concept of 'element' (its coverage), there is no agreement about its *intension* (what a predicate 'says': its sense), nor even about the terminology to be used.

The notion of 'element' has evolved from a philosophical domain to the scientific-philosophical one. The question 'what is an element?' has been a long-standing debate since the dawn of ancient Greek philosophy to the present day. Recently, the philosopher of chemistry Eric Scerri coordinated the publication of *What is a Chemical Element?* which brings together a variety of approaches that aim to provide an update on the current state of the debate about chemical elements. The book welcomes contributions from different perspectives, such as those of historians, philosophers, and chemists with ontological, epistemological, and educational concerns.[1]

In general, two definitions of 'chemical element' coexist in chemistry teaching. The first, due to Lavoisier, defines an 'element' in a macroscopic ontology (simple substance), and the second, usually considered the modern definition, conceptualizes an element in an ontology of particle. In the light of this situation, some authors state that it is time to consider the former conceptualization as merely 'historical' and focus teaching on the basis of the most recent definition.

The aim of this paper is to address this problem from a pluralist perspective by highlighting the pedagogical relevance of incorporating historical-philosophical analyses in the explanation of scientific concepts. To this end, we will begin by recalling the first reflections on the need to distinguish between the concepts of 'element' and 'atom' in Classical Antiquity in Section 2. The first challenge to the doctrine of four elements by Boyle is reviewed in Section 3. Lavoisier's conception of element as 'simple substance' will be discussed in Section 4. The conceptual distinction between 'chemical element' and 'simple substance' given by Mendeleev is discussed in Section 5 and then we will analyze Paneth's treatment of the subject in Section 6. Finally, we will investigate the problem from a new perspective, no longer centred on the assumed dilemma of choosing between the two main definitions, but based on a pluralist approach by highlighting the relevance of historical-philosophical analyses in the explanation of scientific concepts.

ANCIENT TIMES: 'ELEMENTS' AND 'ATOMS'

The dialogue between chemistry teaching and philosophy about 'elementarity' can begin by reflecting on the difference between the concepts of 'element' and 'atom' inherited from classical Greek philosophy. Both concepts are rational abstractions used to account for the existence of material things, their differences and transformations. However, these concepts are linked to distinct philosophical traditions and will influence the theories of matter of future alchemists and chemists. The theory of physical atoms began with Leucippus and Democritus, while the main theory of the elements was developed by Aristotle.

Democritus introduced the term 'atom' (indivisible, though whether theoretically or physically is a matter of dispute) to denote entities that were immutable in form, solid, and of different sizes and weights. These atoms joined together to form compounds that gave rise to different kinds of things in the world, but they retained their identity because they were only juxtaposed to one another, like the letters of an alphabet, which may form different words but themselves remain identical. Democritus' universe is made up of infinite atoms with various geometrical shapes that move in the vacuum without obeying any necessity. [2]

Aristotle's theory of matter was called hilemorphism, because he considered that all material elements had as basic metaphysical constituents form and matter (hyle), which did not exist separately except by abstraction. This theory was based on the acceptance of the existence of four elementary principles (earth, water, air, and fire), themselves products of the association between two essential qualities (earth- dry and cold; water - cold and humid; air - humid and hot; fire - hot and dry) with the homogeneous and inert material substratum, so that the existence of a vacuum was impossible. The four elements were also substances in a philosophical sense. The substance is what underlies properties, which inhere in it. The properties may change, but the substance remains, subsists. Water was the bearer of macroscopic properties such as liquidity, mobility, wetness, and coldness. This is the first sense in which 'element' was conceived: an abstract entity which not only underneath all the other substances but also is the bearer of macroscopic properties. The doctrine of the four elements exerted great influence in Antiquity and, though with some modifications, also in the Middle Ages, when it was common to add ether as the 'fifth element' or quintessence, as postulated by Aristotle. [3]

Although Aristotle and his commentators rejected the existence of indivisible material particles, their doctrine of the continuum did not exclude the idea that combination occurred from minimal particles of matter. Even modern critics of Aristotle, such as Bacon and Boyle, re-signified the concept of minima naturalia in their respective theories of matter, which rejected both atomism and Aristotle's quality-bearing elements, because they resulted from empirical investigations guided by rigorous experimental control. [4]

ROBERT BOYLE: THE CHALLENGE TO THE DOCTRINE OF FOUR ELEMENTS

The doctrine of four elements survives until the Middle Ages, when it slowly began to show some problems. The first step was given by Robert Boyle (1627-1691). In 1661 Boyle published *The Sceptical Chymist* in which the ancient four-element formulation was challenged by demonstrating that the entities called 'elements' were not in fact elemental:

> […] to prevent mistakes, I must advertise you, that I now mean by elements, as those chemists, that speak plainest, do by their principles, certain primitive and simple, or perfectly unmingled bodies; which not being made of any other bodies, or of one another, are the ingredients, of which all those called perfectly mixt bodies are immediately compounded, and into which they are ultimately resolved: now whether there be any one such body to be constantly met with in all, and each, of those, that are said to be elemental bodies, is the thing I now question. [5]

Nonetheless, Boyle traditionally appears in chemistry textbooks and even in some histories of chemistry as the 'inventor' of the modern notion of element: it is said that he defined the elements. He is said to have defined the elements as the indecomposable bodies that make up mixed bodies and into which the latter can decompose. This reference to Boyle's 'revolutionary' definition is now cited by historians as an example of a historical error that consists in abstracting from its context a statement that statement that appears 'true', that is to say, at-present acceptable. [6, 7]

In other words, Boyle was not substituting a modern notion of the element to the Aristotelian definition, but questioned the function of the element in the practice of chemists, that is, the idea of finding units beyond diversity, both principles of genesis and principles of intelligibility of this diversity. The experimental evidence seemed to suggest that those supposedly 'elements' could be broken down in smaller parts. Boyle introduced thus new methods and new tools for the knowledge of matter and the concept of minima naturalia (combination occurred from minimal particles of matter). In fact, Boyle's corpuscles are rather different from Democritus's and Epicurus's atoms and resembling the minima naturalia adopted by chemists in the early part of the seventeenth century. Even as a critic of Aristotle, Boyle resigned the concept of 'minima naturalia', rejecting both atomism and Aristotle's quality-bearing elements. The importance that Boyle attached to chemical experiments in order to prove the existence of corpuscles clearly shows that his chemical theories and corpuscular philosophy were in fact already strictly linked at the outset of his career. His theory of matter is corpuscular, not strictly mechanical, as it includes agents endowed with formative power. According to Clericuzio, "Boyle's chemical and medical works clearly show that he did not subordinate chemistry to the principles of mechanical philosophy. He explained chemical processes in terms of corpuscles endowed with chemical, not just mechanical properties". [8]

But what is the nature of these corpuscles? Boyle separates the hierarchy of materiality into three distinct levels. In *Origine of Forms and Qualities* (1666), he describes what he understands by minima naturalia; then he moves on to describe the second hierarchical level, what he calls second-order agglomerates, formed by the extreme adhesion of the minimal particles. At this moment, a fundamental property for his theory of matter emerges: the texture. And, finally, we have the bodies of the manifest world. Boyle does not resort to the last blocks of matter, but to corpuscles of higher orders of composition. In fact, it is these corpuscular clusters with their respective textures that are responsible for the different natures and properties of matter. [4, 8]

LAVOISIER: ELEMENT AS 'SIMPLE SUBSTANCE'

In the last three decades of the 18th century, chemistry was the scenario of theoretical controversies, experimental innovations, and the establishment of some long-lasting consensuses. One of these controversies concerned with the role of air in combustion, which also engendered the question of the composition of metals (Were they mixtures or simple bodies/elements?), and one of the consensuses reached was the establishment of a nomenclature technique. The history of this period has produced a variety of narratives, coming from different historiographies, as well as diverse ontological, epistemological, and methodological interpretations. Antoine-Laurent de Lavoisier (1743-1794) is the name that occupies the collective memory when it comes to the chemistry practiced in the last three decades of the century.

Following a trend among the chemists of the second half of the eighteenth century, well represented by Pierre-Joseph Macquer (1718-1784), Lavoisier was one of the first to conceive an element as the final stage of chemical decomposition. In the preface of his *Traité Elémentaire de Chimie* published in 1789, he presented his operational or empirical definition of 'element' using as a synonym terms like 'simple body' or 'principle'. According to him,

> If we apply the term *elements*, or *principles* of *bodies*, to express our idea of the last point which analysis is capa-

> ble of reaching, we must admit, as elements, all the substances into which we are capable, by any means, to reduce bodies by decomposition. Not that we are entitled to affirm, that these substances we consider as simple may not be compounded of two, or even of a greater number of principles; but, since these principles cannot be separated, or rather since we have not hitherto discovered the means of separating them, they act with regard to us as simple substances, and we ought never to suppose them compounded until experiment and observation has proved them to be so. [9]

Lavoisier and his collaborators –among them his wife Marie Anne Pierrette Paulze– published the well-known list of 33 elements as 'simple bodies' or 'simple substances'. The term 'element' finds then its reference in the macroscopic domain: observable and tangible simple substances that can be isolated (oxygen, lead, gold, and so on). This operational definition of 'element' is commonly found in several textbooks at the university level. In addition to material 'simple bodies', Lavoisier also grouped among the 'elements', the 'principles' bearing qualities such as the 'caloric principle' and the 'oxygen principle' which attests to its connection with a common conception in the eighteen century, that is, those that considered the 'principles' or 'elements' as 'carriers of material qualities'. [10, 11]

Thus, after many centuries, the notion of 'element' moved from the philosophical domain to the scientific one in Lavoisier's time. An element was no longer conceived as an abstract (unobservable) entity but as an entity that could be isolated and whose properties could be observed experimentally. Lavoisier invites us to think about whether it is possible to experimentally obtain simple corpus or elements (principles).

MENDELEEV: THE CONCEPTUAL DISTINCTION BETWEEN 'CHEMICAL ELEMENT' AND 'SIMPLE SUBSTANCE'

As is known, in the early nineteenth century the English physicist-meteorologist John Dalton (1766-1844) proposed a hypothesis that made it possible to know the relative values of the mass of the 'simple bodies' that combined during a chemical transformation, so that the new concept had no relation with the atomistic philosophy of the Ancients (Democritus, Epicurus, Lucretius). For Dalton, the term 'atom' was associated with the material units that entered into the chemical combinations predicted by the laws of equivalences, simple proportions, and multiple proportions, and received a graphical representation that allowed writing their compounds through formulas. [12]

For the emergence of a new concept of chemical element, the distinction between 'atoms' and 'molecules' proposed by the physicist Amedeo Avogadro (1776-1856) was relevant. This distinction was important for the Russian chemist Dmitri Mendeleev (1834-1907) to point out the difference between 'simple bodies' and 'chemical elements'. Thus, Mendeleev no longer considered these expressions as synonymous, as Lavoisier had done, and the abstract sense of 'element' was gradually replaced by a concept based on the results of experimental work. Mendeleev argued that his periodic classification of the elements had to do with the elements conceived as 'abstract elements' and not with the elements considered as 'simple substances'. According to Mendeleev, the elements in an abstract sense had an essential property: its atomic weight. This property allowed him to order them in a unique sequence.

In the Introduction of his *Principles of Chemistry*, Mendeleev points out that it is important to make a clear distinction between the notion of 'simple substance', understood as isolated homogeneous substance or as an invisible part of the material of a compound body, of the notion of 'chemical element'. Hence, Mendeleev claims:

> The red oxide of mercury does not contain two simple bodies, mercury and oxygen. It is neither the mercury as a metal nor the oxygen in the gaseous form that is contained in the oxide in question, but only the substance of these simple bodies. The elements do not undergo any modification, they are immutable. For example, we find in nature carbon in the form of charcoal, graphite and diamond, which are simple bodies, but made up of a single element, carbon. [13]

The abstract concept of the element proposed by Mendeleev originated from the concept of allotropy. Thereby, the term 'chemical element' no longer denoted the final product of a chemical analysis process, but came to refer to a relational and abstract measure, that is, the atomic masses obtained by experimental techniques. According to Mendeleev,

> […] the elements have an exactly measurable property, that of their atomic weights. The weight of the atom expresses its relative mass or, in other words, an abstraction made from the notion of the atom, this greatness shows the relation that exists between the constituent masses of the independent chemical units, that is, of the elements. [14]

The concept of 'chemical element' denotes a purely abstract entity that does not have an isolated existence, given that it was only possible to identify by its relations of mass with other chemical elements. Mendeleev considered the abstract individuality of the chemical elements as one of the three fundamental laws that govern the Universe. [15] According to him,

> Kant thought that there existed in the Universe two objects that provoked the admiration and veneration of men: the moral law within us and the starry sky above us. Deepening the nature of the elements and the periodic law it is necessary to add a third object: the nature of the elemental individuals who express themselves around us.[16]

PANETH: 'SIMPLE SUBSTANCE' AND 'BASIC SUBSTANCE'

If the existence of allotropes was one of the reasons that led Mendeleev to propose the distinction between 'simple bodies' and 'chemical elements', the discovery of the non-radioactive isotopes by Francis Aston in the 1910s brought considerable difficulties not only to the concept of elementarity, based on the atomic weights, but also to the simplicity of the periodic table that grouped elements into chemically similar families.

The discovery of isotopy posed a threat to the periodic table, as the number of elements as 'simple substances' seemed to increase very rapidly. As the elements were ordered according to their growing atomic weights, it was legitimate to question if these new atoms were manifestations of the same element or, on the contrary, they corresponded to different chemical elements. This episode was known as the 'isotopes crisis' and in the 1920s implied the end of both a 'chemical' way of defining the nature of the elements and the periodic classification that had hitherto been known.

The Austrian Friedrich 'Fritz' Paneth (1887-1958), a pioneer of radiochemistry with a deep philosophical background, solved the crisis by recalling Mendeleev's philosophical distinction between 'simple substance' and 'basic substance'. The discovery of isotopes concerned with new elements conceived as 'simple substances', but the primary criterion of periodic classification involved the element in a more fundamental sense of the term. Experimental evidence in support of that conceptual distinction was provided by Paneth and the radiochemist George Hevesy (1885-1966), which showed that isotopes belonged to the same chemical species in the sense that they exhibited complete replaceability. They based their conception of replaceability or chemical identity on electrochemical experiments in 1913-1914, which showed that the chemical behavior of beta-radioactive lead (Pb-210) was indistinguishable from that of naturally occurring lead (which they believed was just another lead isotope). [17]

The solution proposed by Paneth was based on the observation that the chemical elements with identical chemical properties, but with different atomic masses, had a common physical identity: the atomic number. In fact, since 1916 Paneth suggested associating the number of protons in the nucleus of atoms with the concept of chemical element. [18] After adopting this criterion in 1923 by the newly created IUPAC [19], Georges Urbain (1872-1938) analyzed the chemical and physical reasons for that choice. For him, "this definition has the advantage of solving the isotope question, so that different isotopes of the same chemical element are integral parts of this same element" [20]. This gave rise to what some authors considered the 'modern' conception of an element, which identifies it with its nuclear charge, i.e., with the number of protons in its nucleus.

In 1931, in a conference held in Königsberg, Paneth presented a philosophical analysis of the historical evolution of the concept of 'element', which became a reference for some current debates among chemists and philosophers of chemistry concerning the meaning of 'chemical element'. Paneth suggested a dual interpretation of the concept of 'chemical element' by appealing to Mendeleev's distinction between 'element' and 'simple body'. According to him, it is necessary to distinguish between 'basic substance' and 'simple substance' as different aspects of the chemical element. The latter concept prioritizes the empirical sense with observable magnitudes, whereas the former referred to entities that do not change during chemical reactions. In Paneth's words, the term 'basic substance' denotes "…the indestructible substance present in compounds and simple substances…", whereas the term 'simple substance' refers to "that form of occurrence was meant in which an isolated basic substance uncombined with any other appears to our senses". [21] He emphasized that the most fundamental meaning of the concept of 'element' was its manifestation as 'basic substance'.

Paneth resolved thus the 'isotope crisis' by recalling the ordering of the elements in the periodic system as 'basic substances' and not as 'simple substances, recovering the dual sense of the concept formulated by Mendeleev. If the chemists had focused only on the simple substances, they would have been forced to recognize new 'elements' in each new isotope discovered. Paneth argued then that the periodic table of chemical elements could be retained on the basis that the chemical properties of isotopes of the same element are indistinguishable. [15]

THE TEACHING OF THE CONCEPT 'CHEMICAL ELEMENT': BUILDING BRIDGES WITH THE HISTORY AND THE PHILOSOPHY OF CHEMISTRY

We have briefly reviewed the road from 'element' to 'chemical element'. In general, two definitions coexist in teaching: the first, due to Lavoisier, defines an element in a macrochemical ontology, and the second defines an element in an ontology of particle and was established in 1923 as stated above. A survey of conceptualizations in some of the main textbooks at the university-level allow to appreciate that several definitions are consistent with the operational definition proposed by Lavoisier in 1789. Let's see some examples:

- "An element is a fundamental substance that can't be chemically changed or broken down into anything simpler". [22]
- "Elements are substances that cannot be decomposed into simpler substances by chemical or physical means". [23]
- "A substance that cannot be decomposed into simpler substances by chemical means". [24, 25]
- "Elements are substances that cannot be decomposed into two or more simpler substances by ordinary physical or chemical means". [26]

At the same time, the modern or physicalist definition of 'element' which finds its referent in the atom, is presented in some other textbooks. A couple of examples:

- "A substance whose atoms are all chemically the same, containing a definite number of protons". [27]
- "An element is a substance composed of only one kind of atom". [28]

Ghibaudi *et al*. correctly point out that both conceptualizations are plausible from critics. In the case of the operationalist definition of Lavoisier, the element as 'simple substance' leaves unsolved the persistence of the elements in compounds, probably the greatest mystery in the chemical sciences. On the other side, to identify elements with atoms gives a wrong idea about the existence of the elements within substances. Further, it is possible to claim that from the individuation criterion of an element (that is, its atomic number) solely, it is not possible to determine macroscopic properties like its melting point, its boiling point or its flammability limit.[29]

The concept of 'element' is probably the paradigmatic case of alternative conceptions in chemistry due to its relevance. [30, 31, 32] In the light of this apparent dilemma, some authors suggested that the conception of 'element' in terms of Lavoisier should be considered as purely historical [33,34] whereas Ghibaudi et al. [29] state that it is necessary to take a stand between the two definitions bearing in mind the progress of chemistry. But in another such textbook an element is conceptualized as: "[…] the simplest type of matter with unique physical and chemical properties. It consists of only one kind of atom, and, therefore, cannot be broken down into a simpler type of matter by any physical or chemical methods". [35]

The particularity of this definition lies in the fact that involves the two ontologies implied in the discussion, which would seem to complicate even more a possible solution to this problem. In the light of this situation, we consider that this topic gives the opportunity to recall that a problem of interpretation in science is not just a scientific problem (as is generally assumed) but a philosophical-scientific one. This means that a philosophical standpoint is always present in its interpretation. In turn, this implies that there is not a single 'true' solution to the problem but, on the contrary, there are different possible interpretations.

In line with the reductionist approach that prevails in science at present-day, some authors have proposed an interpretation of an 'element' which finds its reference, again, in the atom. For instance, Roundy says: "Each element is defined by its atomic number (or number of protons in the nuclei)" [36] and more recently William Jensen who claims: "…the term element refers to a specific type of nuclei or, more accurately, to a class of nuclei with the same atomic number" [37], definition with which Ghibaudi and coworkers agree.

These physicalist definitions are not without problems. One of them concerns to the conceptual identification between 'element' and 'atom'. As Alex Johnstone has explained, this goes against the psychology of learning. [38] In the case of beginners, it is better to taught progressively, starting with observations at the macroscopic level. We consider that Johnstone's observation is relevant because he remembers us the origin of chemistry as an experimental discipline. In this sense, Lavoisier's and Boyle's definitions of the 'element' are resulting from the experimental work, a constitutive feature of chemical sciences.

Taking this into account, Nelson suggests to define an 'element' as a "substance that does not undergo chemical decomposition into, and cannot be made by chemical combination of, other substances". [39] In a later work, this author formally distinguishes 'element' from 'elementary substance' where the former is defined as "basic type of matter existing as elementary substances that can be interconverted without change in mass", and the latter denotes his previous definition of 'element'. [40]

In the same line, the definition of 'chemical element' given by IUPAC (International Union of Pure and Applied Chemistry) does not seem to illuminate precisely the problem at hand:

1. A species of atoms; all atoms with the same number of protons in the atomic nucleus.
2. A pure chemical substance composed of atoms with the same number of protons in the atomic nucleus. Sometimes this concept is called the elementary substance as distinct from the chemical element as defined under 1, but mostly the term chemical element is used for both concepts. [41]

Although the two definitions are proposed for the same term, they do not cancel the conceptual identification, again, between 'element', 'atom', and 'pure substance'. At the same time, they do not account for the abstract nature of the concept. As we saw above, the abstract sense allows to explain the different allotropes and isotopes of an element from an abstract entity that underlies all of them. Whereas this interpretation has been supported by some authors [18], others adopt a physicalist view of the abstractness leaving aside any metaphysical connotation of the term. [42]

An interesting and little-known definition provided by Robert Luft (1997) appeals to the old sense:

> Element is an immaterial entity without physical or chemical properties, root of a specific chemical species and common feature to his atoms, molecules, ions and isotopes. It is characterized by two data: a symbol and an order number, the atomic number, that indicates the position of the chemical species within the Periodic Table.[43]

According to Scerri [15], this characterisation is used in the French system of chemical education. Having reviewed the two main definitions of the concept of 'element' that can be found in university textbooks, we have seen that both present advantages and difficulties. The situation looks as a dilemma. However, if we admit that neither candidate definition has explanatory priority, that is, if they do not provide a conceptualization absent of problems, it is then reasonable to ask why a single definition should be privileged. The priority of an ontology of particle over a macrochemical ontology is based on the reductionist assumption widely accepted, in general, by chemistry educators and most of philosophers of chemistry.

In the light of the above considerations, we believe that this problem needs to be addressed carefully when teaching. Even though pedagogical recommendation do not fall within our competences, we consider that some philosophical reflections can be valuable to this problem. First, it is important to remember that scientific practice implies a continuous construction of knowledge. If this is accepted, it would seem appropriate to explain to future scientists the interstices, the problems, and the empty spaces faced by scientific knowledge.

We consider that, at advanced level of teaching, the two classical definitions of 'element' reviewed here along with the Luft's definition and, at the same time, the scientific and philosophical problems associated (the historical development of the concept, the different definitions proposed and the limitations of each conceptualization, the domains of reality implied) would allow students to appreciate the very nature of the problems and the different tools and arguments that science and philosophy provides to address them. On the contrary, the teaching of a 'mummified' chemistry, free of conceptual problems and the associated debates, does not reflect the own scientific practice and, from our viewpoint, it should not be replicated when teaching chemistry to the extent possible. [44]

In this regard, we believe that scientific monism, according to which there is only one scientific story about the world that can be told, should be avoided as far as possible as well. There is a vast philosophical literature and a scientific practice that supports this perspective. As Hasok Chang claims in "Is Water H_2O", objective and univocal truth is not an aim of scientific practice. Pluralism must engage in cultivating multiple scientific systems and lines of inquiry, as science is a multi-aim enterprise, not the search of literal truth:

> But why is it better to be pluralistic? Why keep multiple systems of knowledge alive? The immediate reason for this is the sense that we are not likely to arrive at the one perfect theory or viewpoint that will satisfy all our needs […] If we are not likely to find the one perfect system, it makes sense to keep multiple ones. [45]

This topic presents a very important particularity that is necessary to consider in the light of its teaching. Indeed, there are several definitions of 'element' built on two domains of reality coexisting in the teaching praxis. The key point here is to highlight that, in this case, plurality does not imply incompatibility among the definitions. As a result, the alternative conceptions give different images of the notion of 'element'. Thus, instead of choosing only one definition, we do believe that it is richer to introduce the students to the historical-philosophical aspects associated to the notion of 'element' and the problems closely associated to their possible interpretations. This historical and philosophical analysis contributes to the process of emphasizing the discursive dimension of teaching-learning processes of science twin in real classroom situations. At the same time, this approach also contributes to develop argumentative abilities in chemistry students. [46, 47, 48]

Likewise, we consider that at least some of the following questions would deserve to be discuss in the teaching of this subject matter: Is the individuation criterion of an element based on its atomic number enough to explain its properties and the position of a chemical element in the periodic system? Is its complementation with quantum mechanics fully satisfactory to explain the properties of a group in the periodic table? Let take one case that have led chemists and philosophers to heated debates at times. What are the best positions of hydrogen (H) and of helium (He) in the chart? According to their chemical properties or according to their electronic configurations? [49]

In a recent work, Helge Kragh poses an interesting question concerning the ontological status of the superheavy elements, that is, those whose atomic numbers are greater than 102. [50] It is known that the isotopes of those elements have very short life-times and they are detected at nuclear processes. So, in strict sense, they exist just at the time of detection. But in what sense is it possible to claim that they have existence like the ordinary elements?

CONCLUSIONS

The concept of 'element' is a paradigmatic case of alternative conceptions in chemistry teaching. In this paper we have addressed this problem from a pluralist perspective by highlighting the pedagogical relevance of incorporating historical-philosophical analyses in the explanation of scientific concepts. In this regard, after a survey of the different conceptions of the element from antiquity to the present day, it is possible to assert that pluralism is a consequence of a historical and philosophical study of the concept. Thus, this approach makes it possible to overcome the assumed dilemma of choosing between the two main definitions of 'element', which involve two ontologies.

This topic gives us a rather unique opportunity to introduce the history and the philosophy of chemistry at the science classroom. These metadisciplines give a more real picture of science by revealing, explicating or elucidating different aspects of science. In this sense, the analysis reveals that reality implies more than one domain and a wide variety and diversity of scientific constructs. The metascientific studies can also help us to understand the kind of knowledge built by science and, as a consequence, the kind of teaching that should be encouraged to impart to future scientists.

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