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Letters to the Editor
Писма до редакцията

ON THE PLACEMENT OF HYDROGEN AND HELIUM IN THE PERIODIC SYSTEM: A RESPONSE TO CVETKOVIĆ & PETRUŠEVSKI

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In their comments to our article in this journal (Labarca & Srivaths 2016), Julijana Cvetković & Vladimir M. Petruševski (2017) consider our proposal of placing hydrogen and helium in an intermediate position between two families of elements as a "brave attempt", and instead they argue in favour of better positions for these elements in the periodic system based on very well-known chemical information.

The authors are right when they claim that our view was already proposed in the past. Moreover, it is possible to find similar placements for hydrogen and helium in present-day literature (for example, Ali et al., 2017). However, to the best of our knowledge, the difference between our view and those other proposals is based on the epistemological analysis that leads to such positions for the two elements. Our approach identifies and analyses in conceptual terms the main candidates to be considered the secondary criterion for classifying the elements (electronic configurations, triads of elements, and electronegativity). On this basis, we conclude that neither of these criteria has explanatory priority over the others. This means that all of them have the same epistemological status when it comes to deciding the placement not only for hydrogen, as Cvetković & Petruševski (2017) agree with us, but also for helium. The new chart proposed in our article has the virtue of showing both the chemical and the physical ontologies (i.e. a table based on chemical and physical properties, in the first case, and based on electron configurations in the second one), which are considered irreconcilable in general, but without forcing to choose one of them. This is relevant because the information about the elements that those criteria give us is preserved.

In relation to the placement of helium, it is known that most chemists tend to reject its inclusion among the alkaline earth metals. However, the chemist Henry Bent (2006) has devoted a book to support the Janet left-step periodic table. As is known, helium is placed above beryllium in this chart. According to Bent (2006), this placement yields many regularities in the periodic system (for example, triad rule, group size rule, isoelectric rule, electronegativity rule, first-element distinctiveness regarding congeners, among others). This does not mean that we support a reductionist approach in relation to helium's position in the table, as one of us has clearly pointed out in another work (Labarca, 2013). But if Cvetković & Petruševski (2017) agree with our conclusion concerning a sort of 'balance' among the three identified criteria, then an intermediate position for helium is the result of such an approach. The simultaneous consideration of several criteria for classifying the chemical elements is not alien to contemporary chemical thought. For example, the chemist Lawrence Lavelle (2008) claims:

> [T]he placing of elements in the periodic table is currently accepted as a combination and balance of factors including the following empirical observations: atomic number, properties, periodic trends, and atomic ground-state electron configuration (p. 1482).

After discussing the dissimilarities of hydrogen with both alkali metals and halogens, Cvetković & Petruševski (2017) conclude that hydrogen is a unique element; therefore, they decide to locate it heading the periodic table, assigned to no group, a proposal made by Herb Kaesz & Peter Atkins (2003) some years ago. Placing hydrogen outside of the periodic system implies either that it is not a chemical element, or that periodicity is not a law but a classification. Naturally, since the first option does not look plausible, Cvetković and Petruševski seem to support the second one by saying:

> [T]here are no real arguments, apart from a belief, that 'every element in PT belongs to some of the existing groups of elements (p.169).

This statement implies that the position for hydrogen is no longer discussed but a more basic question arises: the status of the periodic law.

Dimitri Mendeleev proposed his first table in 1869 not merely as a classification of the elements but guided by the need of seeking a sort of definite and exact principle. The idea was finally successful and Mendeleev announced the periodic law in 1871. It is important to remember that this achievement was possible due to his reconceptualization of the term 'element' (Kaji, 2003). Indeed, Mendeleev clearly distinguished between 'simple body' and 'element' which usually were mixed up. An element was conceived as an abstract entity, a 'substance' in a philosophical sense, bearer of properties that give rise to the observable properties of the elements, a conception dating back to the Ancient Greek philosophers. This deep analytical distinction between 'simple body' (or 'simple substance') and 'element' was key for ordering the elements according their atomic weights (Scerri, 2007).

Can the periodic law be considered a scientific law in the light of contemporary philosophy of science? The problem of lawfulness –i.e. the problem of finding the necessary and sufficient conditions, or at least the criteria, which a statement should satisfy to be considered a law– is discussed in philosophy of science at least since 1930. Even though there is not a fully satisfactory elucidation of the concept of scientific law, there is a certain consensus about three criteria that a law-statement should satisfy, namely: truth, logical contingency, and universality. Nevertheless, philosophers of science are aware that the laws of special sciences hardly satisfy the syntactic criterion of universality. This means that most of them are non-strict laws, that is, they contain *ceteris paribus* clauses implicitly or explicitly.

The periodic law is not an exception. It is known that the chemical behaviour of Rutherfordium (104) and Dubnium (105), two super-heavy elements, is anomalous according to their positions in the periodic table due to the pronounced influence of relativistic effects. This exceptionality in the chemical behaviour of these elements does not undermine the lawfulness of the periodic law and, consequently, should not be seen as a challenge to its status.

When compared to Newton's second law or to the Schrödinger equation, both viewed as classical examples of the concept of law, the periodic law appears to be far from lawfulness. However, as several studies show, the laws of chemistry must not been seen necessarily as the laws of physics. The absence of a formalism, or even the approximate nature of the chemical periodicity, does not invalidate the periodic law as a law statement. The periodic law expresses a well confirmed regularity and exhibits an accurate predictive power (remember Mendeleev's predictions on the elements gallium, germanium and scandium) (*cf.* Christie, 1994; Scerri & McIntyre, 1997; Vihalemm, 2003; McIntyre, 2016). To sum up, the periodic law deserves to be considered as a scientific law and, consequently, we do consider that hydrogen is subject to it.

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