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# An element of atomic number zero?

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In this article I address the problem of the status of the element of atomic number zero or "neutronium", a suggestion proposed by Andreas von Antropoff in 1925 seven years before James Chadwick's announcement of the existence of the neutron, by analyzing Philip Stewart's arguments to defend such a proposal. On this basis, I will conclude that it is more cautious from both a scientific and a philosophical standpoint, to think of the neutron just as a structural component of an element.

## 1. Introduction

In 1925 the German chemist Andreas von Antropoff suggested the existence of a new form of matter composed of neutrons. This hypothetical new element, which he called ''neutronium'', would be an aggregate of neutrons able to react chemically with other elements. The proposal was formulated seven years before James Chadwick's announcement of the existence of a new elementary particle, the neutron, and four decades before the observation of the first neutron star. During the following decades, several representations of the periodic system included neutronium as an element.

## 2. A brief history of its origin

The idea of including elements in the periodic table[1] with atomic weights lower than that of hydrogen finds its origin at the end of the nineteenth century.[2] In 1886 J. E. Reynolds built a periodic system placing the elements on a single curve according to their valence and atomic weight. He then claimed that there must be a new period of elements having hydrogen as its 7th member. Samuel Haughton, two years later, concluded that elements with atomic weight between 0 and 1 might have something to do with heat, light, or electricity.

According to van Spronsen,[2] Nikolai Beketov was the first, in 1903, to include the famous ether and the electron as structural components of all elements. In 1904 Dmitri Mendeleev[3] himself assumed the existence of two new elements, *x* and *y*. The former was placed above helium in the zero row of his periodic system and the latter above neon in the first row next to hydrogen. The element *x*, according to Mendeleev, could be the ether with an atomic weight of no more than 0.17, and he suggested the name ''newtonium'' for this entity. This new ''element'', along with coronium, were included in the chart drawn by Sima Losanitsch[2] in 1906 as the first two elements before hydrogen. In his particular helical design, Georg Schaltenbrand[4] proposed the existence of an element 'null' in 1920. During the first decades of that century, there were several attempts to insert subatomic particles into the periodic table. For instance, Johannes Rydberg[2] considered the electron with an atomic number of 0 as a homologue of helium, and Louis de Broglie[5] thought the neutrino to be at the left of neutronium.

On the basis of his previous work of 1925,[6] in 1926 von Antropoff[7] published an original periodic table which envisaged a top left place for an element of atomic number zero, that is, with no protons and electrons. In his chart von Antropoff placed the yet undiscovered element ''neutronium'' above helium (Fig. 1).

In a letter published in *Nature* in 1933, William Harkins[8] claimed that the suggestion that neutrons exist as separate atoms was made independently by Lord Rutherford and himself, with a few months of difference, in 1920. In a recent work, Fontani *et al.*[5] discuss this priority claim in detail.

Some authors considered the von Antropoff's proposal unacceptable and suggested that the proton should occupy that place.[2] Nevertheless, other researchers took the existence of this alleged element seriously. For example, in 1929 Charles Janet[4] placed the element zero above helium in his circular-like chart. Soon after the announcement of the discovery of the neutron,[9] G. N. Antonoff[2] assigned it the place 0 in his periodic system.

The neutron and also the electron found their places in the system designed by E. I. Achimov[2] in 1947, above hydrogen and helium, respectively. Edgar Emerson,[10,11] in 1944 (Fig. 2), John Clark,[12] in 1950, and George Glocker and Alexander Popov[13] in

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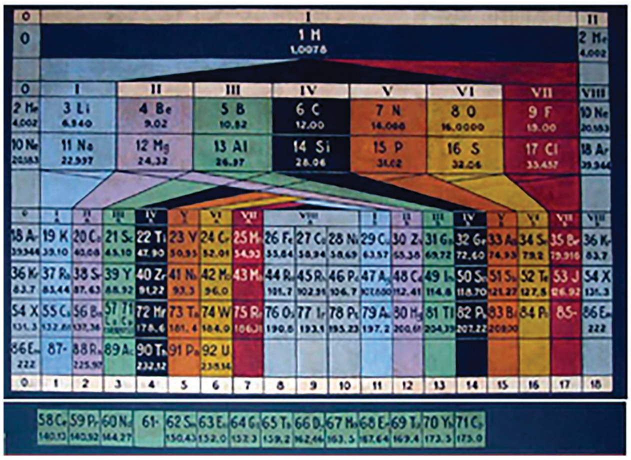

Fig. 1 Andreas von Antropoff's periodic table, a mural at the University of Barcelona, Spain. Reprinted from C. Mans, *Quim. Ind.*, 2010, **587**, 36–40.

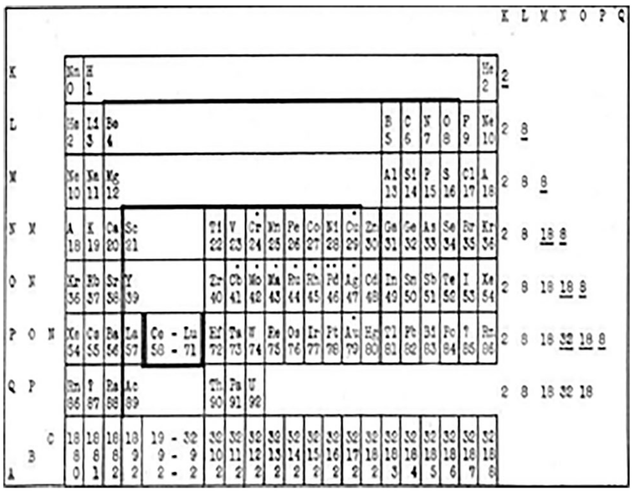

Fig. 2 The periodic table depicted by Emerson (1944). Reprinted with permission from E. I. Emerson, A Chart Based on Atomic Numbers Showing the Electronic Structure of Elements, *J. Chem. Educ.*, 1944, **21**, 254–255. Copyright 1944 American Chemical Society.

1951 also reserved a place for the neutron in their charts, and conceived it as the first member of the noble gases. In the next decade, Torolf Ternstrom[14] introduced a new zero period with neutrino (above hydrogen) and neutronium (above helium) as a complementary proposal. Finally, Luis Bravo[15] also included neutronium into the noble gases family in his spiral design.

## 3. The present-day proposal: a critical review

Nowadays, the Oxford researcher Philip Stewart[16] is the main supporter of the existence of the element of atomic number zero. His spiral chart, named *Chemical Galaxy*, also leaves room for this supposed element (Fig. 3).

After the brief historical review of the roots of this proposal, two questions may be raised: (a) what are his arguments to support this view?; and (b) if one concedes that neutronium is in fact an element, why should it be a member of the noble gases family?

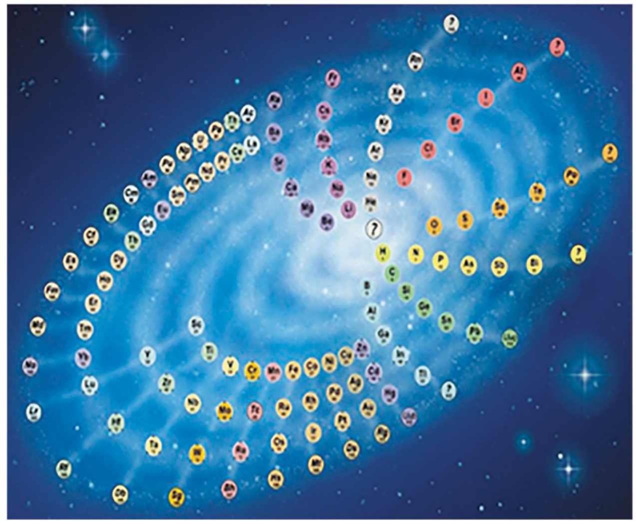

Fig. 3 The periodic table of Philip Stewart (2004). Reprinted from P. J. Stewart, A New Image of the Periodic Table, *Educ. Chem.*, 2004, **41**, 156–158.

Stewart[17] develops different arguments as responses to possible objections to the existence of neutronium as an element. The first of those objections, although not the most relevant, appeals to the absence of neutronium on earth; consequently, it would be futile to assign it a name. On the contrary, the author emphasizes the existence of neutronium as a flux of thermal neutrons both in laboratory and in industry, and proposes that in some contexts it would be simpler to refer to it as ''neutronium gas''.

On the basis of the two above questions, I will divide my analysis in two sections. The first will concern the problem of the nature of the elements, a central notion to discuss Stewart's proposal. The properties of neutronium to be considered as a possible member of the noble gases family will be addressed in the second one.

### 3.1 On the nature of the concept of ''element''

The concept of ''chemical 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 the discussions about the nature of the periodic system and of the problem of natural kinds. With the revival of the philosophy of chemistry in the middle of 1990s, some chemists, philosophers of chemistry and historians of chemistry sought to clarify this notion. But at present the disagreements are deep: while there is a broad consensus about its extension of the concept (its coverage), there is no agreement about its intension (what a predicate ''says'': its sense), nor even about the terminology to be used.[18]

The question 'what is an element?' has been a long-standing debate since the dawn of the ancient Greek philosophy to the present days. In this context, at least two senses in which the term ''element'' is currently understood have been identified.

The first reflections on the subject were formulated by the earliest Indian, Chinese, and Greek naturalists. The theory of matter formulated by those different traditions assumed that there were a small number of primary substances or ''elements'' in nature to which all the other substances could be reduced. In ancient Greece, Empedocles elaborated the so-called ''doctrine of the four elements'': water, air, earth, and fire were the constituent parts of natural reality. These elements were made of particles representing the first four Platonic solids (tetrahedron, octahedron, icosahedron and cube). Thus, some of the Greek philosophers believed that such elements were formed by microscopic components of various shapes, which explained the diversity of their properties.

The four elements (earth, water, air and fire) were also substances in a philosophical (in particular, metaphysical) 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.

In 1661 Robert 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. 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.

At the end of eighteenth century, Antoine-Laurent de Lavoisier was one of the first to conceive an element as the final stage of chemical decomposition. In 1789 Lavoisier and his collaborators – among them his wife Marie Anne Pierrette Paultze – published his famous 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 general chemistry books.

It appears so that the abstract sense of ''element'' was gradually replaced by a concept based on the results of experimental work. However, the abstract or unobservable sense of the term ''element'' was revalorized by the Russian chemist Dmitri Mendeleev in the second half of nineteenth century.[19] He 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 1930s an influential article written by the Austrian radiochemist Fritz Paneth[20] laid the basis for further discussions on this epistemological problem. The author upheld Mendeleev's philosophical distinction and introduced the terms ''simple substance'' and ''basic substance''.

In 1913 Henry Moseley established that the atomic number was a better criterion than the atomic weight for ordering the elements. Based on this point, on the one hand, and on Paneth's works with the isotopes, on the other, in 1923 the IUPAC (International Union of Pure and Applied Chemistry) amended the essential property of a chemical element from atomic weight to atomic number.[21] This gave rise to the modern definition of chemical element: atoms with the same number of protons in the atomic nucleus.

Having reviewed the different senses in which the term ''element'' is conceived at present, it seems to be clear that the key point in the discussion deals precisely with the interpretation of that concept, and Stewart does not elude it. Indeed, the author claims that if an element is defined as ''a form of ordinary matter in which all atoms contain the same number of protons'',[17] there would not be reason to reject neutronium's existence as an element. It is important to analyze the definition of ''element'' proposed by the author. Appealing to the modern or reductionist definition of ''chemical element''[22] to settle the problem of the status of ''neutronium'' faces a very basic problem: its number of protons is zero. This observation is closely related to another possible objection addressed by Stewart: even if one accepted ''neutronium'' as an element, it could not be a member of the periodic system because of lacking chemical properties. Stewart argues that the same objection could be applied in the case of the inclusion of the ''inert'' gases into the periodic table, which nevertheless can be justified on the basis that ''the absence of chemical behaviour is itself a property''.[17] My observation here is that Stewart's last two arguments to defend the status of ''neutronium'' violate an ontological principle about concrete things: there are not negative properties, that is, the absence of a property cannot be a property of the entity itself. This implies that the absence of protons or of chemical behavior cannot be used as argument in favor of the existence of this supposed new element.

### 3.2 On the membership of ''neutronium'' to the noble gases group

The second question concerns the arguments for placing ''neutronium'' at the head of the noble gas family. According to the modern viewpoint that seems to dominate chemistry, the outer electron shells are responsible for the chemical behaviour of an element. An element of atomic number zero has no electrons, and thus chemistry should be absent. Stewart himself mentions this objection, but he does not offer an answer in his article. Likewise, it is known that in a periodic table the groups of elements usually share similar properties. Thus, one might wonder which properties of ''neutronium'' would allow it to be a member of the noble gases.

Although Mendeleev himself failed to predict this family of elements, previously called ''rare'' gases and ''inert'' gases, at least two researchers, William Sedgwick and Jörgen Thomsen, published works in which they predicted the existence of inactive elements. The prediction was finally corroborated when argon, the first element of the series of noble gases, was discovered in 1894. This new group of elements represented a great challenge to the periodic system.[2,19]

The noble gases are the least reactive elements. Their relatively non-reactivity can be understood in terms of their particularly stable ground-state valence electronic configurations, $ns^2np^6$. In this sense, many chemists believed that it was impossible to synthesize a stable molecule of any element of this family. Furthermore, some failed attempts of preparing compounds of noble gases[23–26] had led to the conclusion that the elements of this group (helium, neon, argon, krypton, xenon, and radon) were indeed inert.

The breakthrough came in 1962 when Neil Bartlett[27] prepared the first compound containing a noble-gas atom, a landmark in the history of inorganic chemistry. Almost at the same time, two research teams led by Rudolf Hoppe[28] and Howard Claasen[29] synthesized the compounds $XeF_2$ and $XeF_4$, respectively. Since then, there has been a deeper understanding of the chemistry of noble gases. Several neutral compounds containing atoms of argon, krypton, xenon, and radon have been predicted and synthesized.[30–33] This means that only the lighter helium and neon await the synthesis of their compounds, a great challenge for experimental chemistry, even though some studies predict them to be reactive under suitable conditions.[34]

These remarks attempt to highlight the fact that the noble gases exhibit chemical behavior, unlike the ''gas neutronium'', a supposedly new member of that family. After 90 years of von Antropoff's suggestion, there are reports about an entity made up of two neutrons, the so-called ''dineutron'', as a product of nuclear decay,[35] although its existence is not generally accepted.[36,37] There have also been discussions about the possible existence of the ''tetraneutron''.[38] But those reports do not make reference to possible chemical reactions of those entities with other elements. It might be argued, as in the case of the ''inert'' gases, that it is necessary further research to discover the properties of this hypothetical element. This strategy, nonetheless, would find a relevant theoretical objection since Walter Kossel[39] in 1916 and Linus Pauling[40] in 1933 predicted the existence of compounds of xenon and krypton, a fact verified experimentally some decades later by Bartlett, as mentioned above.

## 4. Conclusions

Summing up, should neutronium be considered as a new member of the periodic system to be placed as the first element of the noble gases? In light of the arguments put forth by Stewart, it is difficult to avoid the conclusion that there are no solid scientific bases at present to support this controversial hypothesis. The existence of a flux of thermal neutrons and of neutron stars does not imply *a priori* that these kinds of matter belong to the natural kind ''element'', one of the main notions of the world of chemistry. In this sense, the concept of ''element'' advocated by the author is inconsistent with his own defense of the proposal. In the same way, the arguments by which ''neutronium'' should head the noble gases family are absent. The idea that an entity formed by an ''atom'' only of neutrons – devoid of protons and electrons – can be considered as an element that exhibits chemical properties is inconsistent, at least at present, with the theoretical framework underlying molecular chemistry: quantum mechanics. In my view, it seems more cautious from both a scientific and a philosophical standpoint, to think of the neutron just as a structural component of an element. Last but not least, the controversy about the status of the element of atomic number zero also shows – more than 140 years since Mendeleev published his first mature periodic table – that the problems of the foundations of the periodic table are still alive.

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