



In praise of triads

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Abstract

The article begins with a response to a recent contribution by Jensen, in which he has criticized several aspects of the use of triads of elements, including Döbereiner's original introduction of the concept and the modern use of atomic number triads by some authors including myself. Such triads are groups of three elements, one of which has approximately the average atomic weight of the other two elements, as well as having intermediate chemical reactivity. I also examine Jensen's attempted reconstruction Mendeleev's use of triads in predicting the atomic weights of three hitherto unknown elements, that were subsequently named gallium, germanium and scandium. The present article then considers the use of atomic number triads, in conjunction with the phenomenon of first member anomaly, in order to offer support for Janet's left-step periodic table, in which helium is relocated into group 2 of the table. Such a table features triads in which the 2nd and third elements of each group, without fail, fall into periods of equal length, a feature that is absent in the conventional 18-column or the conventional 32-column table. The dual sense of the term element, which is the source of much discussion in the philosophy of chemistry, is alluded to in further support of such a relocation of helium that may at first appear to contradict chemical intuition.

Keywords Triads · Periodic table · Left-step table · First member anomalies · Element

In praise of triads

The purpose of the present article is to re-examine the status of triads of elements in the light of modern knowledge as well as some current debates concerning the periodic table. In addition, I will respond to some criticisms raised by William Jensen against my previously published ideas on chemical triads (Jensen 2021). I begin with my response to the criticism, before moving on to the more positive part of my article.

As Jensen reminds readers in his paper, triads of elements were first discussed by the German chemist Wolfgang Döbereiner in the early 1800s (Döbereiner 1829). Jensen

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immediately launches into a critique of Döbereiner by declaring that, to a modern reader, Döbereiner's article is.

...a mess in that it contains inconsistent data, inconsistent symbolism, and a failure to state its underlying assumptions.

Needless to say, some of these criticisms may be justified, but one could say the same of most scientific discoveries when they were first conceived (Scerri 2016a, b). Jensen's dislike for triads seems to overshadow the fact that their discovery can be interpreted to mark the very first hint of chemical periodicity (Scerri 2020). As is well known, the explanation for any valid triad, such as the classic example of lithium, sodium and potassium, is that the interval between the first and second member of the triad is equal to the interval between the second and third member or, in other words, it captures the essence of chemical periodicity.

This and similar triads of elements that were originally found, represent a very significant discovery which paved the way for what is perhaps one of the major discoveries ever made in chemistry, namely that of the mature periodic table. It goes without saying that the periodic table is the most central icon and organizing principle in the whole of chemistry (Scerri 2019). Surely whatever inconsistencies Döbereiner may have committed can be forgiven, in view of the fact that his triads marked the start of this hugely influential development. Similarly, the fact that some of Döbereiner's groupings of elements later turned out to be incorrect, in the light of the subsequently discovered periodic table, is neither here nor there, especially as he was using pre-Karlsruhe values for atomic weights.¹

According to Jensen, Döbereiner's inconsistencies, which I will not enumerate here, lead us to formulate two questions.

1. Do elements known to be chemically analogous via other criteria automatically form triads?
2. Can the formation of triads be used to predict which elements are chemically analogous?

Jensen seems to answer the first question in the affirmative, although he later qualifies his position. However, he categorically rejects the second one and dubs it as the "Döbereiner fallacy". Jensen then proceeds to lament the fact that other chemists of that era, including Ernst Lenssen, indulged in what he terms the "triad fad".

Having illustrated a high failure rate among Lenssen's proposed triads, Jensen further states that,

these abysmal results would have been sufficient to consign the triad concept to the dustbin of history, but rather remarkably, in recent years it has once more been revived by two well-known authors on the periodic table (p. 38)

Since I am one of these authors, along with the late Henry Bent, I feel somewhat compelled to respond in order to clarify my own use of triads. First of all, I should stress that in attempting to search for new triads it was never my intention to predict which elements may be chemically analogous.

¹ The Karlsruhe conference took place in 1860 and one of the most significant outcomes was the widespread adoption of a rationalized and more accurate set of atomic weights for the elements, as suggested by the Italian chemist Cannizzaro (Ihde 1961).

H 1																	He 2														
Li 3	Be 4											B 5	C 6	N 7	O 8	F 9	Ne 10														
Na 11	Mg 12											Al 13	Si 14	P 15	S 16	Cl 17	Ar 18														
K 19	Ca 20											Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36				
Rb 37	Sr 38											Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54				
Cs 55	Ba 56	La 57	Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86
Fr 87	Ra 88	Ac 89	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102	Lr 103	Rf 104	Sg 105	Bh 106	Hs 107	Mt 108	Ds 109	Rg 110	Cn 111	Nh 112	Fl 113	Ml 114	Lv 115	Tl 116	Ts 117	Og 118

Fig. 1 A 32-column periodic table. The elements Ga, In and Tl do not represent a valid triad since the 2nd and 3rd elements in this sequence belong to periods of different lengths

As I will explain, I was attempting to correct what I regard as anomalous aspects of the modern periodic table. The one and only new triad that I may have created, was not necessarily intended to contain *chemically analogous* elements, since I do not believe that chemical properties should be regarded as the main criterion for the classification of elements, a theme that I will also return to in due course.

The mere fact that the periodic table was discovered by chemists, does not necessarily imply that only they should have the last word when it comes to grouping the elements together. Given that the periodic table has been almost completely explained by quantum mechanics, it is to perhaps to this theory that one should look for ways to resolve any remaining discrepancies. One can point to important precedents of this kind, such as when physics came to the rescue of the periodic table by providing the criterion of atomic number in place of atomic weight, that chemists had previously been using to order the elements (Scerri 2018, 2020).

I shall return to these points later but let me go back to Jensen's article. Although Jensen concedes that the use of atomic number triads, that Henry Bent and I have proposed, brings certain advantages such as the occurrence of whole numbers rather than fractions, he immediately points out that,

Thus, for consecutive group 3 elements, the average of the atomic numbers of Ga and Tl gives a value of 56 for In rather than its actual value of 49.²

But surely as Jensen is well aware, valid triads only occur if the second and third elements belong to periods having equal numbers of elements. As Fig. 1 shows, this is not the case for the three elements that Jensen has chosen as his example.

In fact, only about 50% of all possible vertical triads on the periodic table are actually valid and significant, due to the well-known fact that period lengths appear to be 'doubled', apart from the first very short period consisting of just two elements.

The author commits the same error when he is quick to point out that the elements Kr, Xe and Rn also fail to form a valid triad. Again, this is because a valid triad requires that the interval between the first and second element be the same as the interval between the

² The modern label for this group is 13 rather than 3. Why Jensen should prefer the outmoded designation of group 3 is not clear. Furthermore, if he was referring to the older group numbering scheme, he should perhaps have designated the group as III A in keeping with the outmoded North American nomenclature.

second and the third one. This cannot happen unless the second and third element in question fall into equally long periods.³

After an unnecessary formal analysis Jensen finally reaches the same conclusion and writes,

In other words, to form an atomic number triad the two elements being averaged must be equally spaced on the atomic number scale above and below the element in the center of the triad.

Having reached this conclusion, Jensen insists on pointing out that neither Ga, In and Th nor Kr, Xe and Rn form triads. Instead, he adds the further apparently startling conclusion that,

...not all elements within a group are necessarily equally or even approximately spaced with respect to their atomic numbers and atomic weights.

Jensen then attempts to mount what he seems to regard as a conclusive logical argument. After pointing out that advocates of atomic number triads, such as myself, would reject triads such as Al, As and I which are evenly spaced but chemically dis-analogous, Jensen states that it would therefore be circular to use triads to find chemically significant triads. As I implied earlier, I am not aware that I have ever claimed to do so, but I will defer dealing with this issue in full for the moment.

Jensen then makes another two statements to end that particular section of his paper rather abruptly.

1. Chemically analogous elements do not automatically form triads.
2. Triad formation is neither necessary nor sufficient to establish chemical relatedness.

Although one can readily agree with both of these statements, they fail to address the purpose to which Bent and I have deployed atomic number triads. What both of us have claimed, is that a more regular periodic table, which accords better with quantum mechanics, can be obtained while also producing new triads.

Of course, I cannot speak more specifically for Bent, but my own purpose for doing so was not to obtain chemically analogous elements, but as a byproduct of attempting to find a more regular periodic table. In my earlier publications (Scerri, 2008), which Jensen cites, I did attempt to solve the long-standing problem of the placement of hydrogen by suggesting that it should be placed into the halogen group. I also pointed out that doing so would result in the creation of a new triad, namely H, F and Cl.

But this is clearly not a case of using triads to obtain chemically analogous elements as Jensen is implying. It is rather an attempt to resolve the question of the placement of hydrogen, which is already known to be analogous to the halogens in many respects, and a desire to support this view by appealing to triads.

In any case this particular example, the only one in which I claimed to have created a new triad, is now entirely academic, since I have completely withdrawn this proposal in a more recent book (Scerri 2019). I no longer believe that hydrogen should be placed among the halogens but have returned to fully supporting the left-step periodic table as first

³ This is not the case for the s-block in the conventional format of the periodic table, a point that is taken up later in this article.

proposed by Charles Janet in which H remains in group 1, while He is placed in group 2. Here is what I wrote in withdrawing my earlier claim,

In the first edition of this book and until quite recently I had proposed considering the formation of a new atomic triad in order to settle the question of the placement of hydrogen... However, appealing this proposal might seem, I now think that it may represent a mistaken strategy. My reason for saying so is that the first members of groups of elements are never members of triads and there is no reason to believe that a group such as the halogens should represent an exception (Scerri 2019, 139–140).⁴

Mendeleev and triads

Jensen's next section consists of an attempt to understand how Mendeleev used triads in arriving at the predictions for the atomic weights of the elements that were eventually discovered and named gallium, germanium and scandium. Jensen correctly mentions that Mendeleev never used the term triad in his writing and yet "indirectly implied that he made them" when he illustrated the method that one could use to predict the atomic weight of the element selenium, which was known at the time (Mendeleev 1871).

In fact, Mendeleev may be said to have used triads with a vengeance since he employed a vertical triad consisting of S and Te and in addition the two flanking elements in the same horizontal period, namely As and Br. As Mendeleev points out, the value predicted by taking the average of these four flanking elements is 79, which compares rather well with the then known experimental value of 78 for the atomic weight of selenium.

	S (32)	
As (75)	Se = ?	Br (80)
	Te (127.5)	

$$\text{Se} = (32 + 75 + 80 + 127.5) / 4 = 79$$

Jensen turns next to some speculations as to how Mendeleev may have used a similar procedure in the case of predicting the atomic weights of Sc, Ga, and Ge.⁵ As Jensen correctly states, each of these cases presents something of a problem for the use of two intersecting triads in that one does not have the atomic weights of the four required flanking elements (see Fig. 2).

In the case of scandium, Jensen very reasonably claims that Mendeleev might have simply used the average of the weights of the of the two horizontally flanking elements, namely calcium and titanium to obtain a prediction of 44 as reported in Mendeleev's extensive article of 1871.

Jensen then writes,

⁴ To be precise, He, Ne and Ar do form an atomic number triad in the conventional format of the periodic table, although I believe this to be a false triad for reasons discussed elsewhere in the present article. I thank a reviewer for making this point.

⁵ Mendeleev famously did not elaborate on precisely how he made these predictions and many scholars of the periodic table have tried to reconstruct his arguments and none of them entirely successfully. For example, Mendeleev's biographer, Michael Gordin comments on this issue (Gordin 2019).

Jensen's response to this mismatch is to suppose that Mendeleev imported the predicted atomic weight of Ga, or 68 and was thereby able to still take the average of four flanking elements, three of them having measured atomic weights and the fourth one having a predicted value as shown below.

	68	
Si (28)	--	Sn (118)
	As (75)	

$$(28 + 75 + 118 + 68) / 4 = 72.3, \text{ rounded to } 72$$

Remarkably enough, this wonderful piece of numerology on the part of Mendeleev, if correctly reconstructed by Jensen, succeeds in predicting the atomic weight for Ge that Mendeleev published, namely 72. To cap things off, this value also coincides, to two significant figures, with the atomic weight that was eventually determined experimentally when this element was discovered.

One cannot help wondering why the calculations for the weights of Ge and Ga were not conducted the other way round? Why did Mendeleev not use the incorrectly predicted value for Ga obtained by averaging over three flanking elements (74) in order to calculate the atomic weight of Ge by taking an average of four flanking elements, three of which were known at the time and the fourth which would have been available as a result of the above calculation?⁶

Si (28)	--	Sn (118)
	As (75)	

$$(28 + 118 + 75) / 3 = 73.6, \text{ rounded to } 74$$

	Zn (65)	
Al (23.7)	--	In (113)
	74	

$$(27.3 + 65 + 113 + 74) / 4 = 69.8, \text{ rounded to } 70$$

Was Mendeleev just fortunate to have opted for the first choice rather than the completely equivalent second choice that I have suggested? Maybe so, or perhaps Jensen, who argues so strenuously against triads and other forms of numerology, has provided an ad hoc reconstruction that is specifically designed to reproduce Mendeleev's published predictions.

Could it also be that Mendeleev did perform the calculation by taking the average of 3 elements to obtain 74, and then the average of four elements to obtain 70 followed by

⁶ Furthermore, Jensen's attempted reconstruction of Mendeleev's predictions bears an uncanny similarity with the previously published reconstruction by Campbell and Pulkkinen, which Jensen fails to cite (Campbell and Pulkkinen, 2020).

taking the average of these two averages to obtain 72? There are of course many possibilities if one wants to indulge in numerology in the way that Jensen does.

How did Mendeleev make his 1869 predictions for the atomic weights of the three famous elements?

It is also interesting to test how valid Jensen's reconstruction might be by considering Mendeleev's first periodic table of 1869 which already included predictions for the atomic weights of the three famous elements. It seems unlikely that Mendeleev only used triads in his article of 1871 and not in this earlier one. How then do the triads based on the 1869 table match with Mendeleev's predictions of the same year? The short answer is not very well, something that casts further doubt on Jensen's reconstruction of Mendeleev's 1871 predictions (Fig. 3).

Let us begin with how Mendeleev might have predicted the atomic weight of the element that eventually became known as scandium. Mendeleev's prediction on this table is 45. Did he arrive at this value by considering the average of the two flanking elements as Jensen tells us he did in 1871? Unfortunately, this is not the case, since the average of Ca = 40 and Er = 56 is 48.⁷ Did he obtain his prediction by taking the average of three

Fig. 3 Mendeleev's first periodic table, dated 1869 (Mendeleev 1869)

преимущественно найти общую систему элементов. Вотъ этотъ опытъ:					
			Ti=50	Zr=90	?=180.
			V=51	Nb=94	Ta=182.
			Cr=52	Mo=96	W=186.
			Mn=55	Rh=104,4	Pt=197,4
			Fe=56	Ru=104,4	Ir=198.
			Ni=Co=59	Pl=106,6	Os=199.
			Cu=63,4	Ag=108	Hg=200.
H=1			Zn=65,2	Cd=112	
	Be=9,4	Mg=24	?=68	Ur=116	Au=197?
	B=11	Al=27,4	?=70	Sn=118	
	C=12	Si=28	As=75	Sb=122	Bi=210
	N=14	P=31	Se=79,4	Te=128?	
	O=16	S=32	Br=80	I=127	
	F=19	Cl=35,5	Rb=85,4	Cs=133	Tl=204
Li=7	Na=23	K=39	Sr=87,6	Ba=137	Pb=207.
			?=45	Ce=92	
		?Er=56	La=94		
		?Yt=60	Di=95		
		?In=75,6	Th=118?		

⁷ Another possibility might be taking the average of Ca (40) and Ti (50), which happens to yield 45. However, this would appear to be arbitrary, since Ti does not flank the question mark in Fig. 3 that is now occupied by Sc. I thank a reviewer for this suggestion.

flanking elements, namely $\text{Ca}=40$, $\text{Ce}=92$ and $\text{Er}=56$? Once again taking this average gives a prediction of 59 which is of course nowhere close to the published value of 45. It is also worth noting that Mendeleev's originally published prediction of 45 is in fact closer to the actual atomic weight of the element whose contemporary value is 44.9559, as compared with his 1869 prediction of 44.

Next, we could try to see how Mendeleev predicted a value of 68 for the atomic weight of the element that was eventually called germanium. Following Jensen's reconstruction for the 1871 predictions would suggest that Mendeleev took the average of the three flanking elements, namely $\text{Al}=27.4$, $\text{Zn}=65$ and $\text{Ur}=116$. This yields a prediction of 69.4 which when rounded gives 69 but not Mendeleev's published value of 68.

As a final note on the question of how Mendeleev might have made his predictions, I would like to draw attention to an interesting article by Lente, who provides some alternative and persuasive pathways to arrive at the values that were published in Mendeleev's articles of 1869 and 1871 (Lente 2019).

Be it as it may, this whole discussion of how Mendeleev might have made his predictions, does not seem to serve Jensen's assault on triads very well, since broadly speaking it shows that even atomic weight triads are in fact a useful, if not exact, instrument in making predictions. Moreover, the prediction of atomic weight is rather academic from a modern perspective, since these values are subject to the vagaries of isotopic abundances. While some elements like scandium have just a single stable isotope, others like tin can have as many as 10 or so. Observed atomic weights are of course weighted averages over all the contributing isotopes for any particular element which are governed by nuclear stability and the underlying nuclear physics, which operates at an altogether different energy scale to the domain of chemistry. Meanwhile, atomic number triads do not suffer from such issues, since isotopes of the same element share the same atomic number.

The role of triads in the left-step periodic table

Let me finally turn to the positive part of this article, in which I will argue for the continuing value of atomic number triads and how they can guide us to a more general and perhaps more fundamental version of the periodic table. More specifically, I will provide support for the view that Charles Janet's left-step periodic table provides such a more fundamental periodic table.

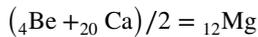
First of all, consider a 32-column representation of the periodic table in which several atomic number triads have been highlighted as colored strips (Fig. 4). As was stated earlier, genuine atomic number triads occur whenever the second and third elements fall into periods which have equal lengths. For example, this is true of the Si, Ge, Sn triad as highlighted in Fig. 4. However, there are some exceptions to this trend, namely the genuine atomic number triads that occur in the s-block of the table.

If we revisit the classic triad of Li, Na and K for example, it becomes clear that it is the first and second elements that belong to equally long periods. How, if at all, can this apparent anomaly be removed? The answer lies in turning to Janet's left-step table shown in Fig. 5 (Janet 1930). Here every single valid triad as shown in the colored strips consist of elements whose second and third elements belong in equally long periods.

Secondly, this alternative table also removes another apparent anomaly which occurs in the conventional format of either the the 18 or 32-column versions of the periodic table. This is the well-known fact that all period lengths repeat apart from the first very

short period consisting of just two elements which rather mysteriously fails to repeat. Meanwhile, the left-step periodic table features not one, but two, very short periods each of which consists of just two elements, namely H and He, followed by Li and Be.

Yet a third anomaly in the standard periodic table is also removed on focusing on the left-step table. In the conventional format, shown either as 18 or 32 columns, the first member of each group is not part of an atomic number triad, with the exception of groups 2 and 18. For example, Be, Mg and Ca form an atomic number triad with the inclusion of the first member of the group, beryllium.



Once again, this anomaly disappears in the left-step periodic table as seen in Fig. 5, since beryllium is no longer the first member of group 2. The first three elements in the modified group 2 are now He, Be and Mg which no longer form a valid triad with the result that group 2 is no longer anomalous. At the same time, the anomaly whereby the noble gases do feature a triad which includes the first member, as is the case in the conventional table, is removed. Group 18 now features the first three elements of Ne, Ar and Kr which does not constitute a triad.

There is even a fourth anomaly which can be successfully removed by appealing to the left-step table. As is well known, the first member of groups of main group elements generally shows anomalous chemical behavior (Kutzelnigg 1984; Rayner-Canham 2020; Wang et al., 2020). For example, beryllium in group 2, boron in group 3, nitrogen in group 15 all show chemical properties which are rather different from those of their fellow group members.

According to Rayner-Canham, who summarizes some of the causes of this so-called “uniqueness principle”, second period elements (Rayner-Canham 2020, 126–127),

Have exceptionally small atomic radii

Exhibit a maximum of four bonding electrons

The non-metallic elements have an enhanced ability to form multiple (π) bonds.

According to Kutzelnigg (1984),

The essential difference between the atoms of the first and higher rows is that the cores of the former contain only s-AOs, whereas the cores of the latter include at least s- and p-AOs. As a consequence, the s and p valence AOs of first row atoms are localized in roughly the same region of space, while the p valence AOs of higher row atoms are much more extended in space. This has the consequence that for the light main group elements both lone-pair repulsion and iso-valent hybridization play a greater role than for the heavy main group elements. Furthermore, this implies that single bonds between first row elements are weak and multiple bonds are strong, whereas for the second or higher row elements single bonds are strong and multiple bonds weak.

In the left-step table the first member of group 2 now becomes helium which is indeed extremely anomalous in comparison to the alkaline earth elements that lie below it. As a result, the typical chemist’s objection to placing helium among the alkaline earth elements can be countered by supposing that this represents an extreme case of first member anomaly. Finally, theoretical analyses of first member anomalies have also been given by Kaupp (2014) as well as Wang et al. (2020) among others.

Proposal for an enhanced uniqueness effect for 1 s elements

In this section I will focus more specifically on the notion that first members of the main groups of the periodic table are not members of triads, regardless of whether one considers atomic weights or atomic numbers.

For example, Schwarz emphasizes the following features which according to him make the 1 s orbital “very special”,⁸

the 1s orbital is very special for 3 reasons:

(i) The 1s shell is the only orbital of all (nearly) neutral atoms and molecules that ‘sees’ an attracting unscreened point-center; the 2sp shell ‘feels’ a slightly screened atomic attraction center $Z-1s^2$, the higher shells 3sp or 3d4s or 4sp, etc. ‘feel’ a strongly shielded atomic core.

(ii) There is no other orbital energetically close to the 1s, so 1s is single and is neither easily polarized nor hybridized (such as 2s2p or 3d4s, etc.) nor is there any strong s2-p2 two-electronic configuration mixing (that is the big difference, from the quantum-theoretical point of view, of $1s^2$ and $2(sp)^2$). In other words, 1s is alone, but for any $n > 1$, the ns orbitals are not alone and hybridize.

(iii) The overlap of 1s is very special, see for instance (Kutzelnigg, Schwarz 1982); or: H-1s binds to transition metal atoms with TM-(n-1)d,ns, while most other ligands such as Cl, OH₂, CN etc. bind with TM-(n-1)d. In contrast to all other atoms, the proton can easily be inserted in the electron density distribution of other atoms or ligands; while all other atoms have occupied core shells, and the Pauli principle causes Pauli repulsion and restrains that interaction.

The proposal for an enhanced uniqueness effect for the elements H and He gains further support from a fact that Bent and also Jensen⁹ have stressed in the literature, namely that the anomalous behavior of the first member of groups decreases as one moves from the s-block to the f-block. William Jensen, whose views formed the subject of the earlier parts of the present article has this to say in an article written 35 years ago (Jensen 1986, 506).

While it is true that H is unique relative to other IA elements, this is really a reflection of a systematic variation in the periodic table which shows that the elements in the first row of any new electronic block tend to show abnormalities relative to the elements in later rows of the same block, and that the degree of divergence decreases in the order s-block >> p-block > d-block > f-block.

The ‘much greater than sign’ following the mention of s-block elements is especially relevant for the proposal of an enhanced uniqueness effect which would further support placing the element He at the top of group 2 rather than its traditional position at the top of the noble gases.

⁸ Private correspondence with Eugen Schwarz.

⁹ Bent goes as far as to call this the Mendeleev-Jensen effect.

The relationship between quantum mechanics and the periodic table

A more general objection that is sometimes raised against the left-step table is that the periodic table was discovered in the domain of chemistry and that chemists believe that they have a right to design a periodic table that serves their concerns. Chemists almost seem to believe that the periodic table is their ‘personal property’ that should not be tampered with, or modified, in response to any demands from physicists. The fact that helium has two electrons in a single shell and therefore seems analogous to the elements in group two, which have 2-outer shell electrons, is generally dismissed on the grounds that electronic configurations do not always reflect chemical behavior (Vernon 2020).

What I would like to propose here is that the fact that the periodic table was first discovered by chemists does not give them the right to dictate what should be regarded as the most fundamental form of the periodic table. Quantum physics has succeeded in almost completely explaining the periodic table by appealing to first principles.¹⁰ If the time-independent Schrödinger equation is solved for the hydrogen atom it emerges that 3 distinct quantum numbers are required to specify each of the solutions. Furthermore, the relationship between the three quantum numbers that characterizes the solutions can also be derived. To these three quantum numbers one must add a fourth quantum number or spin. On combining the possible values of these four quantum numbers, one can rigorously predict that successive electron shells contain 2, 8, 18, 32 etc. electrons.

This outcome is surely not a coincidence but a sign that the periodic table fundamentally reduces to quantum mechanics.¹¹ If one accepts that this is the case there should be no undue alarm at the notion of wanting to make the current periodic table more regular as required by the underlying physical theory. Similarly, there should be no concern with the desire to regularize the manner in which atomic number triads appear on the periodic table. Even more elementary perhaps is the wish, on the part of some periodic table scholars, to place helium into the alkaline earth elements because of their analogous electronic configurations (two electrons in He as compared with two outer-shell electrons in the alkaline earth metals).

The attempt to regularize triads on the periodic table so that they all feature the second and third elements in equally long periods is just one of several arguments in support of the left-step table as the most fundamental form of the periodic table. This claim does not amount to using triads to decide which groups certain elements belong to. It is rather a case of applying atomic number triads, along with other arguments, aimed at arriving at the most fundamental periodic table. The fact that helium ends up in group 2 is merely a byproduct of this search for more regularity and fundamentality.

¹⁰ In earlier articles I pointed out the lack of a complete reduction of the periodic table but as I have also stressed this does not imply that I am in any way attempting to diminish the current achievements that have been obtained through a reductive approach (Scerri 2016a, b).

¹¹ See Scerri (2021) for a recent account of the extent to which the periodic table reduces to quantum mechanics.

A final word concerning 'elements' and simple substances

Much has been written in recent years by philosophers of chemistry about the distinction between abstract 'elements' and elements in the form of simple substances (Scerri and Ghibaudi 2020). Briefly put, the abstract element is a bearer of properties but devoid of any properties apart from atomic weight which serves to characterize it. Meanwhile an element as a simple substance is the manifestation of the element that can be extracted, and represents the final stage in the decomposition of any compound. An element as a simple substance can be identified with the manner in which Lavoisier defined elements. This often-forgotten distinction was at the heart of Mendeleev's thinking about the periodic table and who believed that the periodic table was primarily a classification of abstract elements rather than simple substances. One of the features of abstract elements as discussed by Mendeleev is that these entities have no properties as normally conceived and are characterized just by their atomic weights that remain invariant throughout any chemical reactions.

There has been a great deal of debate as to how this notion should be interpreted. Some authors like Paneth (Paneth 1962), who was the person responsible for reviving this question in the philosophy of science, have insisted that one should not attribute a microscopic interpretation to this notion. Some including Ruthenberg emphasize the transcendental nature of abstract elements which are also alluded to by Paneth (Ruthenberg 2009, 2020). Meanwhile Hendry has criticized the tendency of some authors to think of this view of elements as being somehow transcendental in the sense of being literally metaphysical, meaning beyond the physical realm (Hendry 2006).

In previous writings I have tended to agree with the Mendeleev-Paneth-Ruthenberg approach, especially when it comes to the question of whether one should adopt a microscopic approach to understanding abstract elements. My reason for doing so was largely because Mendeleev was against atomic theory. But it now occurs to me that this may not be sufficient grounds for retaining this view. Clearly Mendeleev held incorrect views on many subjects including his doubting radioactivity, the existence of the electron, ionization theory, valence theory when it was first proposed, the importance of triads, Prout's hypothesis, atomic substructure and so on. In addition, this view would be consistent with the opinion expressed earlier about chemists not having sole custody of the periodic table.

I am therefore changing my mind about my opposition to a microscopic interpretation of abstract or basic elements. Clearly atoms do not have any properties as such. Atoms of gold are not yellow colored, nor are they malleable or in possession of any of the usual macroscopic properties that one associates with the element gold. In this way a microscopic view is consistent with the notion that the abstract elements do not have properties while also not falling prey to what may be a form of obscurantism having to do with transcendentalism and an appeal to what if anything lies beyond the physical realm.

Finally, let me return to the question of the left-step periodic table. If the more fundamental basis for the classification of lies with the abstract elements, then it should not matter that helium does not share any macroscopic properties with the alkaline earth elements. Similarly, the elements in group 17 of the periodic table are grouped together because of their atomic properties such as electronic configurations, not because their macroscopic properties are similar since, they consist of two gases (F_2 and Cl_2 , a liquid Br_2 and a solid I_2). Conversely, the atomic properties of helium and the alkaline earth elements are analogous in that He has 2 electrons and alkaline earth metals have two outermost electrons.

Conclusions

To conclude, we have argued that Jensen is incorrect in attempting to deny the importance of triads of elements. We also find that his attempts to explain how Mendeleev made his famous predictions about the atomic weights of gallium, germanium and scandium are not entirely convincing.

In addition to having provided one of the first hints concerning the occurrence of chemical periodicity an attempt to regularize the occurrence of atomic number triads can be used to support the much-debated left-step format of the periodic table. Further support for the left-step table comes in the form of the proposed 'enhanced uniqueness' of the first period of the periodic table which supports the accommodation of helium into group 2.

Finally, it is suggested that the traditional opposition to such a placement relies too heavily on the macroscopic properties of the elements in group 2 and those of helium. According to the alternative, and more fundamental understanding of the concept of an element, the periodic table is primarily concerned with abstract elements. This conception of an element, which has sometimes been termed as element as basic substance, should be associated with the properties of atoms of the elements rather than macroscopic properties. If one accepts this premise, the well-known configuration of the helium atom with its two electrons is more in keeping with group 2 that consists of atoms whose outer shells likewise contain two electrons than it is with the noble gas elements.

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