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The discovery of the periodic table as a case of simultaneous discovery

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The article examines the question of priority and simultaneous discovery in the context of the discovery of the periodic system. It is argued that rather than being anomalous, simultaneous discovery is the rule. Moreover, I argue that the discovery of the periodic system by at least six authors in over a period of 7 years represents one of the best examples of a multiple discovery. This notion is supported by a new view of the evolutionary development of science through a mechanism that is dubbed Sci-Gaia by analogy with Lovelock's Gaia hypothesis.

1. Introduction

The subject of simultaneous discovery is a rather controversial one among scholars who study the nature of science.[1] Generally speaking historians and philosophers tend to focus on individual discoverers and therefore regard simultaneous discovery as something to be explained away as a kind of anomaly. To take just one example, the classic book by Thomas Kuhn is all about scientific revolutions and accompanying radical breaks that are almost invariably associated with one or other individual, be it Lavoisier, Einstein, Planck or Darwin [1].

On the other hand, and not altogether surprisingly, sociologists of science take a broader view of scientific discovery and regard it as something of a collective phenomenon involving many individuals. For sociologists, the phenomenon of simultaneous, or multiple, discovery seems perfectly natural and is regarded as the rule rather than as the exception [2]. In this article, I will argue that the discovery of the periodic table in the 1860s represents an excellent example of a simultaneous discovery, albeit one that took place over a

[1]A list of simultaneous or multiple discoveries in various centuries is given in the following Wiki article, http://en.wikipedia.org/wiki/List_of_multiple_discoveries sampled on 19 April 2014.

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element weight	
hydrogen	1
azot	4.2
carbon (charcoal)	4.3
oxygen	5.5
phosphorus	7.2
sulfur	14.4

Figure 1. Dalton table of atomic weights. Part of an early table of atomic and molecular weights published by Dalton. It contains just five elements in addition to hydrogen that is taken to have the standard atomic weight of one unit. Dalton soon changed the weight of oxygen to eight.

period of 7 years. In doing so, I will be siding more with the sociologists rather than my colleagues in the history and philosophy of science where my own training lies.

Let me immediately say that when I appeal to the sociology what I have in mind is the classical sociology of science as best exemplified in the work of the late Robert Merton [3]. I have no sympathy with the sociological turn that took place following Kuhn's book. This book famously concluded that paradigm changes or scientific revolutions did not occur in a rational manner but were governed by collective gestalt switches and social factors. As is well known, this encouraged sociologists of science to shrug off the view that science provides objective knowledge about the world and allowed them to read social factors into all scientific developments and, in many cases, to even embrace a form of relativism as to the nature of scientific progress. According to this view, somebody like Darwin prevailed in his views on the evolution of species, because social conditions in nineteenth century England favoured the acceptance of his ideas rather than because Darwin had somehow latched onto a piece of the 'truth' about how nature behaves.

2. A brief history of the periodic table

A convenient place to begin to consider the development of the periodic table [4] is with the work of the Manchester schoolteacher John Dalton and his revival of atomic theory. From its origins in Dalton's work in meteorology, there emerged the view that the smallest components of matter consisted of indivisible particles or atoms. Each element consisted of atoms having different weights. The decisive step taken by Dalton was his attribution of relative weights to the atoms of many elements. In doing this, Dalton appealed to experimental data on how much hydrogen combined with any other particular element [5]. He also needed to assume how many atoms of hydrogen combined with how many atoms of the other element in question. This required an arbitrary decision on his part, which he arrived at on the basis of greatest simplicity. He assumed that water, a compound of hydrogen and oxygen consisted of one atom of each element, and it therefore followed that the weight of oxygen that combined with a fixed weight of hydrogen would be taken as the atomic weight of oxygen. In due course, Berzelius and others realized that water consisted of two atoms of hydrogen combined with one of oxygen that led to a doubling of Dalton's original value for the atomic weight of oxygen (figure 1).

Then came the experiments conducted by Gay-Lussac and Humbolt on the combination of gases, where they found that gases combined as a ratio of integral numbers of volumes [6]. Here is a good example,

$$2 \text{ volumes of hydrogen} + 1 \text{ volume of oxygen} \rightarrow 2 \text{ volumes of water vapor.}$$

The only interpretation available to Dalton amounted to the following equation:

$$2\,H + O \rightarrow 2\,OH.$$

But such as equation is not balanced. Furthermore, it is difficult to see how this could even take place given that in Dalton's view atoms of oxygen or any element cannot 'divide' since he supposed atoms to be indivisible. While confusion reigned over the formulae or compounds in general as well as over atomic weights few people seemed to notice that the problem had essentially been resolved by the work of Avogadro, who in 1811 had written that equal volumes of gas under the same conditions of temperature and pressure contain the same number of molecules [7].

If Avogadro's hypothesis is correct, then there are equal numbers of molecules of steam in the products of the above gas reaction as there are molecules of hydrogen at the start. Secondly, there are twice as many water molecules as there are oxygen atoms. It follows that a single molecule of water contains twice as many atoms of hydrogen as it does atoms of hydrogen to give the formula of H_2O rather than Dalton's HO.

Avogadro also put forward the postulate of the existence of diatomic gas molecules. The argument is simple; if the volumes of hydrogen and oxygen were present as single atoms, then they should combine to form as many water molecules as there were atoms of hydrogen and oxygen. But if one assumes that each molecule of hydrogen consists of two atoms as does each molecule of oxygen, then two molecules of hydrogen (four atoms) would combine with one of oxygen (two atoms) to form two molecules of water each of which has the formula of H_2O.

Putting together the correct formula for water as well as the diatomic nature of elemental gas molecules, one could now correctly write

$$2\,\mathrm{H}_2 + \mathrm{O}_2 \rightarrow 2\,\mathrm{H}_2O.$$

Matters came to a head at the famous Karlsruhe conference of 1860 at which Cannizzaro revived Avogadro's hypothesis and produced a set of consistent and more accurate atomic weights [8]. This was a pivotal moment which essentially opened the door for the discovery of the periodic table.

Only now could chemists, physicists and assorted others begin to ponder the relationships between the unifying data provided by reliable atomic weights and the chemical and physical properties of the elements. As is well known, the sequence of increasing atomic weights of the elements provides the ordering principle or the backbone upon which the entire edifice of the periodic table depends. By arranging the elements in order of increasing atomic weight, it becomes clear that chemical periodicity or repetition occurs after regular intervals.

3. The first hints of chemical periodicity

The first hint of chemical periodicity is beyond any doubt due to the German chemist Wolfgang Döbereiner, who starting in 1827 began to discover what we know as triads of elements [9]. He realized that there were several sets of three elements among which one element had an atomic weight that was approximately the average of the other two. For example, sodium has an atomic weight of approximately 23 and thus represents the average of the weight of lithium (7) and that of potassium (39). This fact alone is already suggestive but it becomes even more suggestive when combined with the realization that the chemical and physical properties of sodium are also intermediate between those of lithium and potassium. It therefore appears that a relationship between atomic weights is able to capture a relationship between the properties of different elements.

In retrospect, Döbereiner had essentially discovered chemical periodicity since what underlies the existence of triads is the fact that sodium and potassium occur are regular distances away from lithium in terms of the sequence of increasing atomic weights. But of course Döbereiner did not produce a periodic *table* but only the discovery of several disconnected triads.

Another powerful hint which was to take a longer time to reach full fruition was the discovery made by the Scottish physician William Prout, who was working in London. On examining a list of atomic weights, Prout noticed that the weights of many elements were integral multiples of the weight of the lightest element, namely hydrogen. He arrived at the obvious conclusion that all the elements might be composites of hydrogen. This hypothesis seems to have contributed to the thinking of several of the co-discoverers of the periodic system, although somewhat paradoxically not to the thinking of Dimitri Mendeleev as we will see later. Of course, the hypothesis met with immediate resistance from chemists who pointed out that there were too many exceptions consisting of elements whose atomic weight was nowhere near an integral multiple of the weight of hydrogen. Using modern data, the two best examples are chlorine with an average atomic weight of 35.45 and copper with 65.55.

4. Finally the periodic table, starting with de Chancourtois

To return to my earlier point about the important role played by Cannizzaro in publishing a set of consistent and accurate atomic weights, it should be realized that the first published periodic table, or perhaps one should say periodic system, was achieved a mere 2 years later. This took place in France at the hands of the French geologist Émile Béguyer de Chancourtois [10]. De Chancourtois published a three-dimensional periodic system consisting of the elements arranged in order of increasing atomic weights in the *Comptes Rendus de l'Academie des Sciences*[2] [11]. De Chancourtois arranged his elements as a helical line inscribed onto a metal cylinder. A full turn of the cylinder represented 16 elements and the 17th element appeared directly below the first one. In this way, lithium, sodium and potassium are all seen to lie on a vertical line running along the length of the cylinder and so on for other groups of elements as they subsequently became known. Similarly, the elements beryllium, magnesium calcium and strontium all occur on another vertical line alongside the one just described, along with a few errors from a modern perspective, namely the elements iron and uranium (figure 2).

Unfortunately, the published article, which appeared in three parts, completely failed to include any diagrams of De Chancourtois' system as a result of the publisher's incompetence, thus destroying any visual force that his arrangement might have had. Angered by this omission, De Chancourtois republished his work privately but, as a result, failed to reach the intended audience. He appears to have lost interest in his idea and returned to all manner of other scientific endeavours.

Indeed the work of De Chancourtois only came to light following Mendeleev's Faraday lecture of 1889 in London, when Mendeleev mentioned De Chancourtois' work but added that he, De Chancourtois, had not considered the system as a 'natural one'. This passage appears to have provoked one P. J. Hartog, an English chemist who had studied extensively in France, to rush to defend De Chancourtois' claim in an article published in *Nature* magazine of the same year which begins

> It is well known that the Newlands-Mendeleev classification of the elements was preceded by the discoveries of certain numerical relations between the atomic weights of allied elements due to Döbereiner, Dumas and others; but what has been almost completely ignored is the immense advance made by M.A. E. Béguyer de Chancourtois, a French geologist of note… [12, p. 186]

Hartog went on to give a detailed translation of numerous passages from de Chancourtois' articles and concluded by saying

> It will be well to point out immediately that M. de Chancourtois's system assigns numerical characteristics of the elements a general formula of the form $(n + 16n')$ where n' is necessarily an integer; and his table thus brings out the fact that the differences between the atomic weights of allied bodies approximate in many cases to multiples of 16. Thus we get the parallel series of which our author speaks –

Li		Na		K		Mn		Rb
7	…	$7 + 16 = 23$	…	$7 + 2.16 = 39$	…	$7 + 3.16 = 55$	…	$7 + 5.16 = 87$
O		S		Se		Te		
16	…	$16 + 16 = 32$	…	$16 + 4.16 = 80$	…	$16 + 7.16 = 128$		

[2]De Chancourtois did not cite Cannizzaro by name and some of his atomic weights were slightly different. For a detailed comparison of the atomic weights used by Cannizzaro and De Chancourtois see Van Spronsen [19].

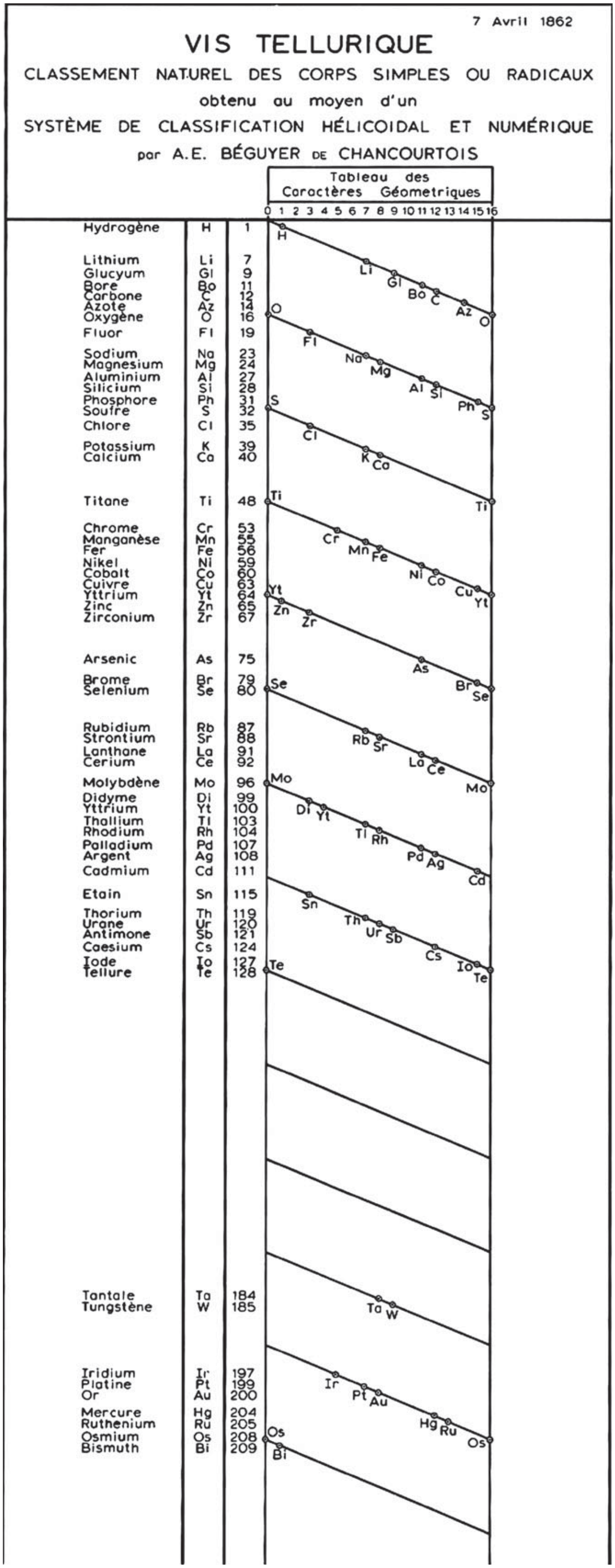

Figure 2. De Chancourtois' helical periodic system.

> As we glance at the first two turns of de Chancourtois's helix we ask ourselves if the discovery of Newlands and Mendeleeff does not lie before us [12, p. 187].

There is no question that de Chancourtois was the first to publish the notion that the properties of the chemical elements are a periodic function of their atomic weights. Or as he put it, the properties of bodies are the properties of numbers.

5. Newlands

The second discoverer of the periodic system was the London-based John Newlands, a sugar chemist and private chemistry tutor, whose lack of a formal academic position may have contributed to the neglect of his work, although he was eventually awarded the Davy medal for his discovery.

As early as 1863, Newlands was classifying elements into a total of seven groups as well as exploring numerical relationships among their atomic weights.

For example, his first group consisted of

> Metals of the alkalis:- lithium 7; sodium 23; potassium 39; rubidium 85; caesium 123; thallium 204. The relations among the equivalents of this group may, perhaps, be most simply stated as follows:-

1 of lithium		+ 1 of potassium		= 2	of sodium.
1	″	+ 2	″	= 1	of rubidium.
1	″	+ 3	″	= 1	of ceasium.
1	″	+ 4	″	= 163,	the equivalent of a metal not yet discovered.
1	″	+ 5	″	= 1	of thallium.

Newlands was mistaken about a new element of weight 163 and in thinking that thallium should be grouped with the alkali metals. However, it is clear that he was willing to make predictions. Contrary to the popular accounts, it would seem that the act of making predictions concerning new elements using a periodic table was not initiated by Mendeleev.

In 1864, Newlands published a short table containing 12 elements to show two series of six elements each of which differs from another one of a set of six by 16 units or very close to it. Another table he published the same year included 33 of the then known elements. Newlands' big opportunity to impress came in 1866 when he gave a presentation to the London Chemical Society. For this event, he produced and even more comprehensive table that contained 62 elements. But in the course of his lecture, he made the ill-fated remark that compared the repetition of elements after intervals of eight with musical octaves. This provoked one of the attendees to ask him mockingly whether he had considered arranging the elements in alphabetical order as this might produce an even better classification.

The members of the London Chemical Society decided not to publish his article although Newlands was able to publish several articles in William Crookes' influential journal, the *Chemical News* [13] (figure 3).

6. William Odling

Unlike the two previously mentioned discoverers, William Odling, who coincidentally hailed from precisely the same London Borough of Southwark as did Newlands, was a prominent academic chemist whose lack of recognition cannot be attributed to his being an outsider to the field or to not having an academic position. Odling variously held the directorship of the Royal Institution, a position which he inherited from Faraday, a Readership at St Bartholomew's Hospital and eventually a professorship at Oxford. In 1864, Odling published the table shown

	no.		no.		no.		no.		no.		no.		no.		no.
H	1	F	8	Cl	15	Co and Ni	22	Br and Ni	22	Pd	36	I	42	Pt and Ir	50
Li	2	Na	9	K	16	Cu	23	Rb	30	Ag	37	Cs	44	Os	51
G	3	Mg	10	Ca	17	Zn	24	Sr	31	Cd	38	Ba and V	45	Hg	52
Bo	4	Al	11	Cr	19	Y	25	Ce and La	33	U	40	Ta	46	Tl	53
C	5	Si	12	Ti	18	In	26	Zr	32	Sn	39	W	47	Pb	54
N	6	P	23	Mn	20	As	27	Di and Mo	34	Sb	41	Nb	48	Bi	55
O	7	S	14	Fe	21	Se	28	Ro and Ru	35	Te	43	Au	49	Th	56

Figure 3. Newlands' table illustrating the law of octaves as presented to the London Chemical Society in 1866 ([13], pp. 113–114). One noteworthy feature is the correct reversal of the elements tellurium and iodine. This is another deed that is generally attributed to Mendeleev.

						Ro	104	Pt	197
						Ru	104	Ir	197
						Pd	106·5	Os	199
H	1	"		"		Ag	108	Au	196·5
"		"		Zn	65	Cd	112	Hg	200
L	7	"		"		"		Tl	203
G	9	"		"		"		Pb	207
B	11	Al	27·5	"		U	120	"	
C	12	Si	28	"		Sn	118	"	
N	14	P	31	As	75	Sb	122	Bi	210
O	16	S	32	Se	79·5	Te	129	"	
F	19	Cl	35·5	Br	80	I	127	"	
Na	23	K	39	Rb	85	Cs	133	"	
Mg	24	Ca	40	Sr	87·5	Ba	137	"	
		Ti	50	Zr	89·5	Ta	138	Th	231·5
		"		Ce	92	"			
		Cr	52·5	Mo	96	V	137		
		Mn	55			W	184		
		Fe	56						
		Co	59						
		Ni	59						
		Cu	63·5						

Figure 4. William Odling's periodic table of 1864, featuring 57 elements, displaying the reversal of Te and I and making a separation between what are today referred to as the transition elements in order to highlight the greater similarity among main group elements.

as figure 4 and which included 57 elements at a time when Newlands was only including 24 elements [14].

Also, unlike de Chancourtois and Newlands, Odling had attended the Karlsruhe meeting and would have had first-hand exposure to the liberating views of Cannizzaro. In fact, on his return to England Odling became one of the strongest advocates of Cannizaro's approach to chemistry.

Perhaps he regarded himself in more of a hand-maiden role than as somebody at the forefront of major discoveries concerning the elements. The fact remains that Odling's work also failed to have much impact on the scientific community of the day and that Odling did not pursue the discovery further. Another possible cause for Odling's failure to develop his periodic system might be that he was more interested in the fundamental science rather than in developing what at the time must have seemed like mere classification.[3]

7. Gustavus Hinrichs

This author is beyond a doubt the most enigmatic and an unconventional among the co-discoverers of the periodic system. His approach included arguments from astronomy, spectroscopy, mineralogy and numerology in addition to chemistry and physics. Hinrichs was a Dane who had fled political persecution by emigrating to the USA. I do not have the space here to discuss his unique approach but suffice it to say that even the manner in which he displayed his most mature periodic system was highly unusual in being of a circular form that included groups of elements displayed as 'spokes' on a bicycle wheel [15]. Further information of Hinrich's fascinating approach can be found in other publications [16] (figure 5).

As with the other lesser known pioneers of the periodic system, Hinrichs' version shows a number of desirable features. To name just one example, Hinrichs has correctly grouped together the elements copper, silver and gold, something that even the great Mendeleev neglected to do in his earliest tables of 1869.

8. Lothar Meyer

Julius Lothar Meyer was born in Heilbron, Germany, and became one of the most influential chemists of his era. He is remembered for his independent discovery of the periodic table, although his contributions tend to be over-shadowed by those of the more illustrious Russian, Dimitri Mendeleev in most accounts. However, as far as mature periodic systems are concerned Lothar Meyer was the first to publish. He had attended the Karlsruhe conference and later recalled Cannizzaro's speech in glowing terms. As he described it, the scales had fallen from his eyes and his doubts had disappeared and were replaced by a quiet feeling of certainty.

Lothar Meyer published his first periodic table in 1862 and included 28 elements. In 1864, he published a textbook which included an updated periodic table that contained 50 elements [17]. In 1869, he developed perhaps his finest table which suffered a similar fate to De Chancourtois' diagram of his helical periodic system. But at least De Chancourtois' article was published even if lacking a diagram, whereas in the case of Lothar Meyer nothing appeared and the table only surfaced 25 years later. It was ultimately published but following such a long delay it did nothing to further its author reputation and was in any case well out of date by then. It has been said that if this table had come to light earlier, it might have made a difference in the priority dispute that Lothar Meyer had with Mendeleev. Lothar Meyer's table appears to be more consistent and more accurate than Mendeleev's including the correct placement of mercury with cadmium, tin with lead and thallium with boron, none of which Mendeleev carried out.

Finally, another symptom of multiple discovery is the frequent occurrence of bitter priority disputes, precisely as witnessed in the case of Lothar Meyer and Mendeleev over many years [18,19] (figure 6).

9. Mendeleev

Dimitri Mendeleev was in fact the last of the six co-discoverers of the periodic system and could benefit from the work of the earlier five pioneers (figure 7). The case is often made that

[3]There is no denying the fact that the three earliest pioneers, De Chancourtois, Newlands and Hinrichs, were all outsiders or even amateurs and that the more professional chemists only entered the arena in the final stages of the 7-year period of discovery.

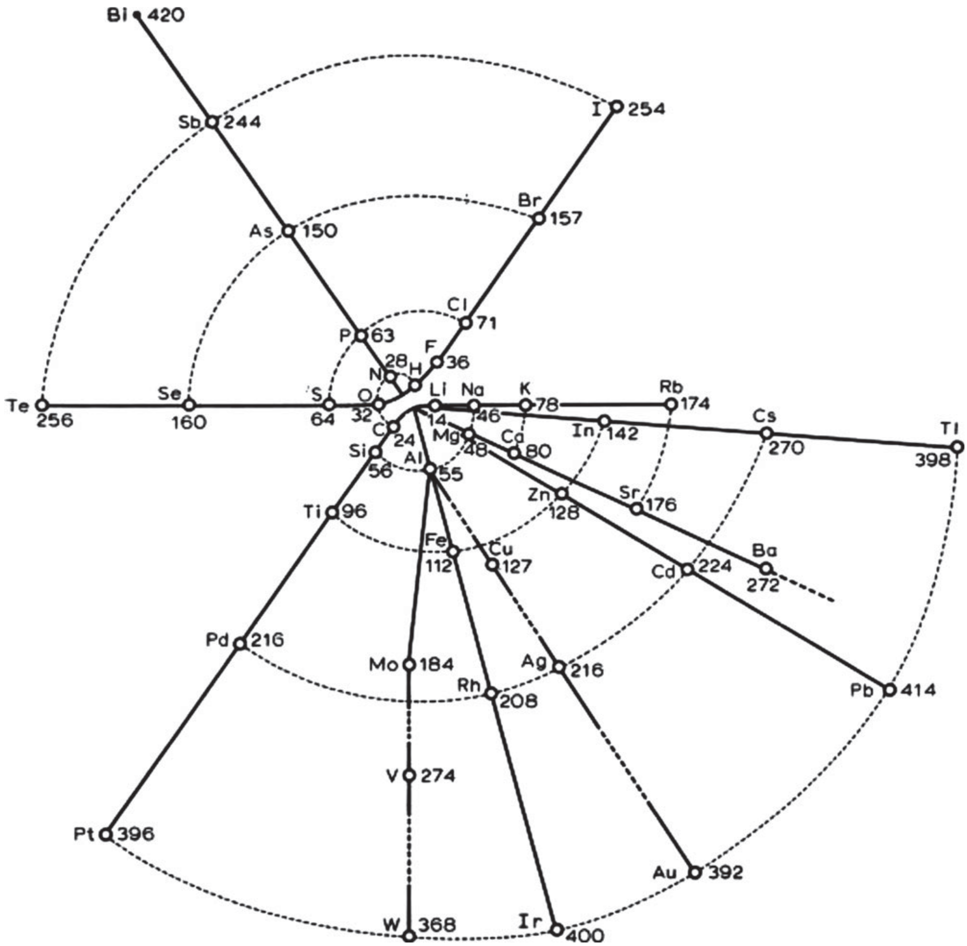

Figure 5. Hinrich's spiral representation of the periodic system. Familiar groups of elements can be seen radiating from the centre of this wheel-like motif.

MEYER'S TABLE OF 1868.

1	2	3	4	5	6	7	8
Cr=52.6	Mn=55.1 49.2 Ru=104.3 92.8=2.46.4 Pt=197.1	Al=27.3 [illegible]=14.8 Fe=56.0 48.9 Rh=103.4 92.8=2.46.4 Ir=197.1	Al.=27.3 Co=58.7 47.8 Pd=106.0 93=2.465 Os=199.	Ni=58.7	Cu=63.5 44.4 Ag=107.9 88.8=2.44.4 Au=196.7	Zn=65.0 46.9 Cd=111.9 88.3=2.44.5 Hg=200.2	C=12.00 16.5 Si=28.5 [illegible]=44.5 [illegible]=44.5 Sn=117.6 89.4=2.41.7 Pb=207.0
9	10	11	12	13	14	15	
N=14.4 16.96 P=31.0 44.0 As=75.0 45.6 Sb=120.6 87.4=2.43.7 Bi=208.0	O=16.00 16.07 S=32.07 46.7 Se=78.8 49.5 Te=128.3	F=19.0 16.46 Cl=35.46 44.5 Br=79.9 46.8 I=126.8	Li=7.03 16.02 Na=23.05 16.08 K=39.13 46.3 Rb=85.4 47.6 Cs=133.0 71=2.35.5 Te=204.0	Be=9.3 14.7 Mg=24.0 16.0 Ca=40.0 47.6 Sr=87.6 49.5 Ba=137.1	Ti=48 42.0 Zr=90.0 47.6 Ta=137.6	Mo.=92.0 45.0 Vd=137.0 47.0 W=184.0	

Figure 6. Lothar Meyer's table of 1868 but finally published in 1895.

MENDELÉEFF'S TABLE I.—1871.

Series.	GROUP I. R_2O.	GROUP II. RO.	GROUP III. R_2O_3.	GROUP IV. RH_4. RO_2.	GROUP V. RH_3. R_2O_5.	GROUP VI. RH_2. RO_3.	GROUP VII. RH. R_2O_7.	GROUP VIII. RO_4.
1	H=1							
2	Li=7	Be=9.4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27.3	Si=28	P=31	S=32	Cl=35.5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Ce=59 Ni=59, Cu=63
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	? Y=88	Zr=90	Nb=94	Mo=96	—=100	Ru=194, Rh=104 Pd=106, Ag=108
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	I=127	
8	Cs=133	Ba=137	? Di=138	? Ce=140	....	....	....	....
9	....	....	....	....	....	....	....	....
10	....	....	? Er=178	? La=180	Ta=182	W=184	....	Os=195, In=197 Pt=198, Au=199
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	....	....	
12	....	....	....	Th=231	....	U=240	....	....

Figure 7. Mendeleev's periodic system of 1871. The first of his many tables was published in 1869.

Mendeleev went well beyond his competitors because he made successful predictions of new elements as well as correcting the atomic weights of already known elements and in some cases the positions of elements in the table [20]. But in the spirit of this paper, I propose to regard him on an equal footing with the other co-discoverers. Since so much has been written about Mendeleev, I will merely refer the reader to the literature and will move on to my concluding sections [21].

Moreover, there has been an active debate among historians and philosophers of science regarding the relative merit of prediction as opposed to the accommodation of already known data over the acceptance of any particular scientific theory or development in general [22]. Much of the debate has focused on the classic example of Mendeleev's predictions. Surprisingly perhaps, not all authors succumb to the traditional view that successful prediction trumps everything. Even more recently Samuel Schindler has proposed that contra-predictions, meaning the correction of atomic weights and re-positioning of elements might have been even more decisive in the acceptance of the periodic table by the scientific community [23].

10. Sociologists of the classical tradition

In addition to arguing the view that simultaneous discovery is the rule rather than the exception the sociologists of science of the classical tradition also carried out much useful work on the related issue of scientific priority.

> We begin by noting the great frequency with which the history of science is punctuated by disputes, often by sordid disputes, over priority of discovery. During the last three centuries in which modern science developed, numerous scientists, both great and small, have engaged in such acrimonious controversy [24, p. 635].

Merton sought to identify the causes of frequent scientific priorities [24]. He began by asking why priority disputes seem to occur so frequently in science. Is it because scientists are especially egotistical and therefore given to establishing their claims in a more vociferous manner than occurs in other fields? Merton quickly dismisses this view.

But as Merton and many others have noted, the protagonists themselves often take little or no part in the ensuing priority debates. It is rather their followers who take it upon themselves to defend the honour of their heroes, frequently because of nationalistic motives. A good case in point was the dispute over the discovery of element 72, eventually named hafnium, that took place between the French and British press on one side and the Danish scientists based at the Niels Bohr institute in Denmark [16].

Yet another factor fuelling priority disputes are the institutional norms operating on individual scientists and placing pressure on them to promote their claims more forcefully that they might do otherwise. Then there is the question of scientific knowledge as a form of 'property'. In commercial or industrial settings, the protagonists generally wish to settle disputes quickly in order to come away with a reasonable share of the monetary profits. In scientific disputes, however, there is generally no money to be made by individual scientists. Consequently, the *only* thing at stake is the reputation of a scientist and little wonder that scientific disputes appear to be more acute than those in other fields.

11. A new approach called Sci-Gaia

I have recently begun working on a view of the development of science that takes the views of the classical sociologists somewhat further. Stated briefly, I regard the development of science in an organic and evolutionary manner. I give to my project the provisional name of Sci-Gaia [25] with deliberate appeal to James Lovelock's view of the Earth as a living evolving organism, which he calls Gaia [26,27]. In my own view, the development of science involves small incremental changes, not Kuhnian leaps and bounds. It involves countless almost random mutations in the thinking of many individuals followed by the survival of only the 'fittest' of these mutations. Science is not progressing towards some objective truth lying 'out there' but is rather being propelled from within or 'pushed from behind' as Kuhn has correctly proposed in this instance. There are no right and wrong theories in science but just steps towards a collective knowledge. In the book that I am writing on this subject, I give numerous examples of intermediate figures in the history of science whose work may have been pivotal even if it may have been regarded as 'wrong' in retrospect.

My favourite example is the case of the theoretical physicist and mathematician William Nicholson, who was the first to propose the quantization of angular momentum in atomic physics [28]. Although this fact is reasonably well known, at least to historians of physics, what is not so well known is Nicholson's accompanying theory based on a completely 'wrong' set of assumptions about proto-atoms that exist in space and give rise to our terrestrial elements. By means of this theory, Nicholson succeeded in accommodating numerous lines in the spectrum of several stellar nebulae and also that of the solar corona. In addition, he was able to successfully predict the existence of some prominent new lines in the spectrum of these astronomical bodies and phenomena. How can such incorrect theories be so successful? On the conventional view of science they cannot. On a view that science progresses as a collective view with a plethora of twists and turns and gradual evolutionary developments, one is not so hard pressed to explain away the success that Nicholson's theory seemed to enjoy.

On this view, priority disputes are a mere distraction or a charade played out by scientists seeking their moment of glory. All that really matters is that scientific knowledge as a whole makes progress. The fight among individuals may serve to bring about better science just as the struggle of life and death between animals in the jungle serves to hone to survival skills of the different species and to thereby improve each of the species. Individuals are relatively unimportant on this view. The heroic view of the history of science whereby we try to attribute a discovery to a particular individual or even a small group of individuals gives way to a more nameless and faceless collective view of the growth of science. Seen in this perspective it is hardly surprising that simultaneous discoveries should be relatively commonplace. The periodic table was not discovered just by Mendeleev or even by Mendeleev and Lothar Meyer at about the same time. It was discovered by at least six individuals working more or less independently of each other in quite different parts of the world and with no communication among them. This happens because when an idea is ripe it is just a matter of time before it is noted by different people at more or less the same time. Of course, these individuals may be committed to developing their discoveries to different extents, which is generally why we give more credit to one or other individual. But this is a matter of who to assign priority to and quite separate from the question of how discovery actually occurs. The question of priority is a rather local one that should not dictate the manner in which the history of science is written and presented. But of course everybody is human and we all still like a hero since it makes for a good story. But it may not make for a good *history*.

In closing, I would go further in proposing that the history of the discovery of the periodic table provides perhaps the best-known example of simultaneous discovery if for no other reason than the fact that it involved at least six individuals by contrast to the more frequently cited cases involving two or three individuals such as Newton and Leibniz, Darwin and Wallace, Weinberg and Salam, Venter and Collins to cite just a few.

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