J. A. R. NEWLANDS' CLASSIFICATION OF THE ELEMENTS: PERIODICITY, BUT NO SYSTEM (1)

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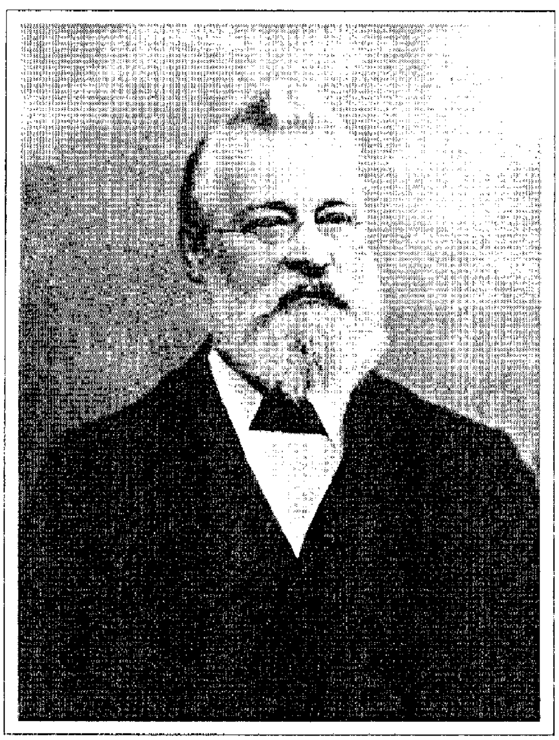
Introduction and Definitions

It seems safe to say that a place in the history of chemistry is assured for J. A. R. Newlands, yet even a century after his death debate continues over just what that place should be (2). Newlands was one of several scientists who published a system for classification of the chemical elements or explored the relationship between atomic weights and chemical properties in the decade following the 1860 Karlsruhe Congress. By the end of that decade the periodic system of the elements had emerged, and the question of priority for that system has engaged both chemists and historians of chemistry ever since. Opinions concerning the amount of credit which Newlands deserves for uncovering the periodic law varied greatly during his lifetime and still continue to do so.

The purpose of this paper is not to argue the relative merits of the contributions of Alexandre Émile Beguyer de Chancourtois, Dmitrii Mendeleev, Julius Lothar Meyer, Newlands, William Odling, and others. Rather, it is to examine the work of one scientist, Newlands, and ask whether that work constituted a periodic system of classifying the elements. The aim of this paper is not an attempt to reconstruct the process or sequence of events which Newlands followed to arrive at his views on chemical periodicity, but an attempt to examine his published views and appraise their validity from a contemporary point of view.



J. A. R. Newlands

A brief summary of Newlands' life is appropriate before analysis of his work. (Details can be obtained from Newlands' obituary in *Nature* (3) and the entry on Newlands in the *Dictionary of Scientific Biography* (4).) John Alexander Reina Newlands was born on November 26, 1837. He spent most of his life in the vicinity of London, where he died on July 29, 1898. He studied at the Royal College of Chemistry and then served as assistant to the chief chemist of the Royal Agricultural Society. He spent part of 1860 on the European continent, but not at the Karlsruhe Congress, a gathering that has been described as necessary for the subsequent discovery of chemical periodicity (5). Instead, Newlands, who was of Italian descent on his mother's side, fought for Italian independence with Garibaldi. In the mid-1860s Newlands published several notes in the *Chemical News* on relationships among equivalent weights, classification of elements, and a relationship he termed the "law of octaves." At the time, the work was the subject of little notice, some criticism, and even some ridicule. During this time, Newlands supported himself as a private analytical chemist and teacher. He later worked at a sugar refinery and concentrated on sugar chemistry, writing several articles and a book (6) on the subject, mainly in collaboration with his brother Benjamin. As the periodic law in the form proposed by Mendeleev and Meyer gained attention and acceptance in the 1870s and 1880s, Newlands began to assert his priority in the matter in articles in the *Chemical News* and in a monograph, *On the Discovery of the Periodic Law and on Relations Among the Atomic Weights* (7). He was awarded the Davy medal of the Royal Society in 1887 "for his discovery of the Periodic Law of the chemical elements," five years after Mendeleev and Meyer were given the same award for the same discovery.

It is necessary to define terms, and in particular to specify what is meant by a periodic system of the elements, before any analysis can be made. Unfortunately, the term periodic system does not have a universally accepted definition. The literature of the history of the periodic system is replete with definitions. Various contributors to the concept of chemical periodicity and historians of that concept even use different terms, including periodic law and periodic table. For example, Mendeleev used the term periodic law (8), a term which Newlands also embraced in asserting priority for his own contributions (7). J. W. van Spronsen, in his classic monograph (5), prefers the term periodic system. In discussing priority, van Spronsen defines a periodic system as, "a sequence of all the (known) elements arranged according to increasing atomic weight in which the elements with analogous properties are arranged in the same group or column." Earlier in the same work, however, van Spronsen refers to "facets of a true periodic system" including additional criteria, for example a distinction between main groups and sub-groups and provision of vacant spaces for undiscovered elements.

I propose a working definition that falls somewhere between van Spronsen's first definition and his true periodic system: a periodic system of the elements consists of a self-consistent arrangement by atomic weight of all the known elements, which systematically displays groups of analogous elements. This definition places considerable emphasis on organization and internal consistency. It does not, however, require the system to be free from error.

This study, in addition, applies to Newlands' work a set of secondary criteria enumerated by Sheldon Lachman for judging scientific theories. Lachman asserts that there are reasons for preferring one theory over another, even in cases where competing theories explain the data comparably well. His list of criteria includes clarity (explicitness and lack of ambiguity), completeness (in accounting for all known phenomena within its purview), coherence (internal consistency among its parts), simplicity (few independent assumptions or poorly defined concepts), fruitfulness (in advancing knowledge), and precision of prediction (9). Lachman's list is a clearly elucidated portion of an expository monograph that presents a traditional view of how science operates. His criteria, however, are representative of characteristics which a broad range of scientists and philosophers of science would expect in adequate scientific theories. Scholars who hold a traditional view of the practice of science (such as Lachman) as well as scholars skeptical of the traditional view (such as Thomas Kuhn) share similar criteria. Kuhn's list of standards for theory evaluation includes accuracy, consistency, scope, simplicity, and fruitfulness. "Together with others of much the same sort," he writes, "they provide *the* shared basis for theory choice (10)."

The Case for Newlands

Although Newlands' work does not meet the criteria for a periodic system set out above, his contributions were substantial. Those contributions extend beyond the tables most often reproduced in discussions of his work, and they include insights which have been misunderstood by critics both in his time and in ours. This section concentrates on Newlands' insights, deferring critical analysis of the shortcomings of his work.

Newlands is best known today for his law of octaves and the tables with which he illustrated that "law." Having arranged the elements in order of atomic weight and assigned an ordinal number to each element, he noticed the following relationship (11):

> It will also be seen that the numbers of analogous elements generally differ either by 7 or by some multiple of seven; in other words, members of the same group stand to each other in the same relation as the extremities of one or more octaves in music. ... This peculiar relationship I propose to provisionally term the 'Law of Octaves.'

Table I accompanied Newlands' first formulation of the law of octaves in 1865. He presented a slightly improved version, shown in Table II, in a paper read before the Chemical Society in the following year (12).

The tables certainly constitute an arrangement by atomic weight of the elements then known. The arrangement shows elements with analogous properties in analogous positions. Newlands remarked (11):

> It will be observed that elements belonging to the same group usually appear on the same horizontal line.

Notice that he did not claim that all elements which appear on the same horizontal line belong to the same group. Indeed, he gave as an example the nitrogen group, which he enumerated as containing nitrogen, phosphorus, arsenic, antimony, and bismuth, an example which lists as a group only some of the elements appearing on the same horizontal line. Newlands can certainly be criticized for not making his rows and groups co-extensive; however, to point to a row in his table and ask what the included elements have in common (as was done in a recent article on the development of the periodic law (13)) constitutes a misreading.

In 1863 and 1864, before formulating the law of octaves, Newlands made several predictions of elements not yet discovered (14, 15, 16). The most striking of these predictions was of an element of atomic weight 73 analogous to silicon, tin, and titanium (15). This element—germanium—was discovered in 1886 by Clemens Winkler. Newlands made this prediction in 1864, before Mendeleev (17), and he reasserted it in print at least twice after promulgating the law of octaves and before Winkler's discovery (7, 18). The prediction of new elements is inconsistent with the law of octaves as Newlands formulated it, but it is important to note that Newlands did not abandon his earlier predictions after putting forward his "law." Newlands' predictions of new elements were based on incomplete triads of chemically similar elements whose atomic weights stood in an arithmetically simple relationship. Early in the 19th century, Johann Döbereiner had been the first to note such triads (complete ones) and to attempt to use them to group elements (19). Typically the atomic weight of

Table I. Newlands' original table illustrating the law of octaves (11)

	No.		No.		No.		No.		No.		No.		No.		No.
H	1	F	8	Cl	15	Co & Ni	22	Br	29	Pd	36	I	42	Pt & Ir	50
Li	2	Na	9	K	16	Cu	23	Rb	30	Ag	37	Cs	44	Tl	53
G	3	Mg	10	Ca	17	Zn	25	Sr	31	Cd	38	Ba & V	45	Pb	54
Bo	4	Al	11	Cr	19	Y	24	Ce & La	33	U	40	Ta	46	Th	56
C	5	Si	12	Ti	18	In	26	Zr	32	Sn	39	W	47	Hg	52
N	6	P	13	Mn	20	As	27	Di & Mo	34	Sb	41	Nb	48	Bi	55
O	7	S	14	Fe	21	Se	28	Ro & Ru	35	Te	43	Au	49	Os	51

Table II. Newlands' table illustrating the law of octaves as presented to the Chemical Society in 1866 (12)

	No.		No.		No.		No.		No.		No.		No.		No.
H	1	F	8	Cl	15	Co & Ni	22	Br	29	Pd	36	I	42	Pt & 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 & V	45	Hg	52
Bo	4	Al	11	Cr	19	Y	25	Ce & 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	13	Mn	20	As	27	Di & Mo	34	Sb	41	Nb	48	Bi	55
O	7	S	14	Fe	21	Se	28	Ro & Ru	35	Te	43	Au	49	Th	56

the triad's middle element was the mean of those of the other two. In 1857, Dumas had examined relationships among atomic weights in groups of related elements (20). Newlands cited Dumas' work, and his own early efforts at classification focused on groups of related elements and the relationship among their atomic weights.

Newlands' prediction of germanium was better than others he made—even apart from the fact that it turned out to be correct. The prediction of germanium was based on more than one piece of evidence, more than one incomplete triad of related elements: namely, silicon, ___, tin and silicon, titanium, ___. An individual triad was a somewhat flimsy basis for prediction, but two supported each other. In addition, the prediction of germanium concerned relatively light atoms which were better known at the time. If the list of elements can be compared to a jigsaw puzzle, it is certainly easier to predict and describe a piece missing from an area of the puzzle with relatively few gaps and whose patterns are fairly well known than to predict a piece missing from an area where gaps abound and possible patterns are little more than speculations.

Besides the prediction of germanium, which was borne out by subsequent events, Newlands and Mendeleev actually shared another prediction, this one incorrect. Both expected that an alkali metal of atomic weight near 170 would someday be found (15, 21). This and other incorrect predictions by Newlands were wrong for the same reason as this and another by Mendeleev, namely the existence of the mostly unknown lanthanide block between the second and third transition groups. The general superiority and specificity of Mendeleev's predictions based on his periodic table are not in dispute. Newlands' most successful prediction was not just a lucky guess, however, and his unsuccessful predictions were no worse than some of Mendeleev's.

Newlands may be credited with speculating about the existence of whole families of undiscovered elements, a speculation borne out by the discovery of the noble gases in the 1890s. Faced with the criticism that his law of octaves left no room for the discovery of new elements, Newlands responded (22):

> The fact that such a simple relation [the law of octaves] exists now, affords a strong presumptive proof that it will always continue to exist, even should hundreds of new elements be discovered. For, although the difference in the numbers of analogous elements might, in that case, be altered from 7, to a multiple of 7, of 8, 9, 10, 20, or any conceivable figure, the existence of a simple relation among the numbers of analogous elements would be none the less evident.

Of course, this statement is not a *prediction* of a family or families of new elements; furthermore, it does not address the usual course of subsequent discoveries of elements (*i.e.*, not in families but as isolated members of already known groups). Still, the discovery of argon did present some difficulties with respect to the periodic system as it then existed because there appeared to be no place for it. Newlands' speculation foresaw that such a discovery need not be problematic.

Newlands must also be credited with associating each element with an ordinal number. Indeed, Wendell Taylor's assessment (23) of Newlands' work called him a "pioneer in atomic numbers" and judged his emphasis on the ordinal number of each element to be "one of the most interesting features of his work." For several reasons, that number is not the same as the atomic number known today. First, the discovery of elements unknown to Newlands would increase the order number he assigned to heavier elements. Also, he assigned the same number to elements whose atomic weights were very close; however, each element actually has a unique atomic number. Finally, Newlands was not aware of the physical basis for atomic number first elucidated by Moseley half a century later (24).

Newlands emphasized that atomic weight and order number were approximately proportional over large ranges of atomic weights. He considered his ordinal numbers as a regularly varying surrogate for the somewhat irregularly varying atomic weights. By focusing on order numbers rather than atomic weights, he could notice that an increment of 7 or 14 was frequently seen between similar elements—even if his tables included some inversions in order number. Newlands proposed the law of octaves, a relationship among order numbers, at virtually the same time as his first paper on this relationship between atomic weights and order numbers (25). He continued to explore the relationship between atomic weight and ordinal numbers well into the 1870s (26).

In fact, Newlands saw the ordering of the elements by atomic weight as one of the innovations for which he deserved credit; he asserted that one of his papers (15) in 1864 (7):

> ..gave a list of all the then known elements in the order of atomic weight, which was the first ever published.

The listing of elements by atomic weight is so common today that the claim sounds incredible. Even though it is not strictly correct (for example, John Hall Gladstone had published such an arrangement (27), albeit with many erroneous atomic weights, in 1853; and even Dalton's incomplete list of unreliable weights was in numerical order (28)), the arrangement was sufficiently unusual even in 1875 that Newlands published a note extolling its advantages in data tabulations (29).

Why Newlands' Insights Do Not Constitute a Periodic System

Newlands' work on classification of the elements exhibited many of the features which are associated with the periodic system today and which won such acclaim for Mendeleev (*e.g.*, recurrences of elements with similar properties, predictions of undiscovered elements). Mendeleev did not simply develop a *better* periodic system than Newlands, however; rather, Newlands' work did not constitute a periodic *system*. This judgment hinges on the word system, with its implications of self-consistency and organization. In short, Newlands' work on classification contains too many inconsistent or poorly defined pieces.

For example, the prediction of new elements, which was so prominent a feature of Mendeleev's system, represents a contradiction in Newlands' work. The law of octaves was criticized at the outset for leaving no room for the discovery of new elements (12). Although Newlands disputed this criticism, the fact remains that the law of octaves left no room for the *prediction* of new elements. His predictions of new elements, including the correct prediction of germanium, were all made before his formulation of the law of octaves, and they were made on the basis of relationships between atomic weights, not order numbers. Newlands' contemporaries, presented with the law of octaves, might reasonably have assumed that he had abandoned his predictions for an arrangement he considered superior. Yet Newlands claimed priority in predicting germanium after Mendeleev's prediction of gallium proved correct but before germanium was actually discovered—in effect reasserting the prediction.

The issue of just how or even whether the law of octaves was consistent with the discovery of new elements presents further instances of inconsistency or lack of clarity. That Newlands foresaw the possibility of new groups of elements has already been noted. His response to the far more common occurrence of the discovery of a new element or a re-evaluation of an atomic weight, however, reveals a logical difficulty (22):

> As a proof, however, that new discoveries are not very likely to destroy such relationship, I may mention that when the existence of the "law of octaves" was first pointed out (*Chemical News*, August 20, 1864), the difference between the numbers of P and As was 13 instead of 14, as between As and Sb, and also between Sb and Bi. Since then, by the determination of the atomic weight of indium, the difference of the numbers of P and As has been made to be 14, as in the other cases adduced.

His argument here would be faulty, even if he had placed indium correctly. The insertion of indium between phosphorus and arsenic caused the latter elements to fall into octaves; it should be obvious that insertion of another element in a similar way would disrupt whatever octaves already existed. The point here is not a simple misclassification, a problem which beset even Mendeleev; it is the logical necessity of misclassification when new elements or new atomic weights are discovered. In a system with no empty spaces, the only ways an octave relationship can be preserved upon the discovery of an intervening element is for that element to share a position already occupied (a possibility in Newlands' classification, albeit one he did not emphasize) or to displace an already existing element from its position in the table. In the latter case, there must be some error in classification, either before or after the new element takes its position.

An attempt of systematization can be seen in Newlands' 1878 article in the *Chemical News* (18) and the introduction to his 1884 monograph (7). In addition to asserting his priority in formulating the periodic law, he provided a checklist of specific instances in which he applied that law. This striving for system came late, and, in my judgment, actually accentuates the lack of organization among his many and substantial contributions. The items on the list are drawn from several papers, including items, such as the prediction of germanium, which predate the law of octaves or whose connection to it is tenuous at best. One item on the list, his prediction of the atomic weight of the newly discovered element indium, was hardly unequivocal (30):

> The equivalent of indium, then, may prove identical, or nearly so, with those of zinc or cadmium. ... It is also just possible that indium may occupy a position in the zinc group similar to that of thallium among the alkali metals, in which case the equivalent of indium would be 182, or thereabouts.

In fact, he ended up incorporating indium into his table just before arsenic. Several of the items on the list of applications were not original, such as recognizing the superiority of Cannizzaro's atomic weights, attempting to explain numerical relations between atomic weights, and (as already noted) ordering the elements by atomic weight. Newlands' collection of applications culled from various papers is clearly deficient by comparison with Mendeleev's extensive list of deductions which accompanied his periodic system from the outset (17, 21).

The close juxtaposition of articles in Newlands' monograph (7) also accentuates their lack of continuity. For example, in the second of two articles (15) on relations among atomic weights, he referred to the relationships he established in the earlier article—even though the two articles involve different sets of atomic weights (14)! That is, in the second paper he specifically cited the first paper's atomic weight relationships among related elements (*e.g.*, lithium, sodium, and potassium; or chlorine, bromine, and iodine) without noting that in the second paper he employed a different system of atomic weights. The two articles originally appeared a year and a half apart, but their proximity in the monograph underlines the discontinuity of atomic weight systems despite the constancy of conclusions.

Assessment with Lachman's Criteria

Because Newlands' contributions lack systematic organization, his work does not fare highly with respect to Lachman's criteria of clarity or coherence. Newlands was undoubtedly misunderstood in his day and continues to be today. At least part of this persistent misunderstanding can be attributed to incomplete or unsympathetic reading. The notion that the fanciful name "law of octaves" prevented Newlands' contemporaries from taking his work seriously has become commonplace (31). As noted above, the idea that the rows in his tables are co-extensive with chemical families is a misreading, and the criticism by one of his contemporaries that consecutive elements such as iron, nickel, and cobalt are assigned to different groups was likewise a misreading. Even Mendeleev confused Newlands' octaves with groups of related elements (32); but Newlands' poor exposition of his ideas must surely bear part of the blame for some misunderstandings.

Newlands' work does not measure up well against Lachman's criterion of precision of prediction. Although Newlands' clarifications of the misreadings just mentioned prevent some incorrect deductions from being made from his law of octaves, they greatly reduce the possibility of making any deductions from the law. For example, stating that "elements belonging to the same group usually appear on the same horizontal line" does not allow the reader to deduce which, if any, of the elements in the same horizontal row as nitrogen belong to its chemical family. Newlands also noted "that elements having consecutive numbers frequently ... belong to the same group (16)." Thus the classification leaves open the possibility that nitrogen is related to carbon or oxygen. Newlands knew precisely which elements were related to nitrogen; however, his classification does not specify that knowledge. For this reason, the classification does not earn a high rating for completeness either. (In another sense the classification was complete, however, for it included every element known at the time.)

Simplicity is another criterion in which Newlands' work earns a mixed rating. On the one hand, the law of octaves and the tables which embody it are simplicity itself: order the elements by atomic weight, filling a table which contains seven rows. Even the instruction to put two elements in the same space if their atomic weights were close enough is simple. The few inversions in atomic weight order (Table II contains fewer than Table I) are not simple, however, even where they are correct (such as placing iodine with the halogens and tellurium with the chalcogens). As just noted, knowing which elements are a part of groups, among the candidates simply identified by the table, is not simple at all.

Finally, Newlands' work must be ranked low in fruitfulness. This criterion is unlike Lachman's others in looking beyond the theory itself to its reception by other scientists. By all accounts, Newlands' work was not influential in the development of the periodic system used today. Neither Mendeleev nor Meyer, the two scientists honored in 1882 with the Davy medal for their work on the subject, was influenced by Newlands.

Close examination of Newlands' work is worthwhile not only as an interesting episode in the history of chemistry but also as a case study in the development of an area in science. Normal progress in science is rarely systematic. Observations from a variety of sources, often seemingly unrelated, are accumulated in a somewhat random manner. The scientific community does not require that each new piece of information be explained before it is published. Indeed, such a requirement would be counterproductive, effectively stifling the cross fertilization of ideas in which one investigator follows up on an anomaly first reported by another. Seen in this context, Newlands' work is solid, original, and important.

The great discoveries in science, however, often involve syntheses, explanations of a body of information. Moreover, if there is one activity in science which demands a systematic exposition, it is classification! In this area Newlands falls short of genius.

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