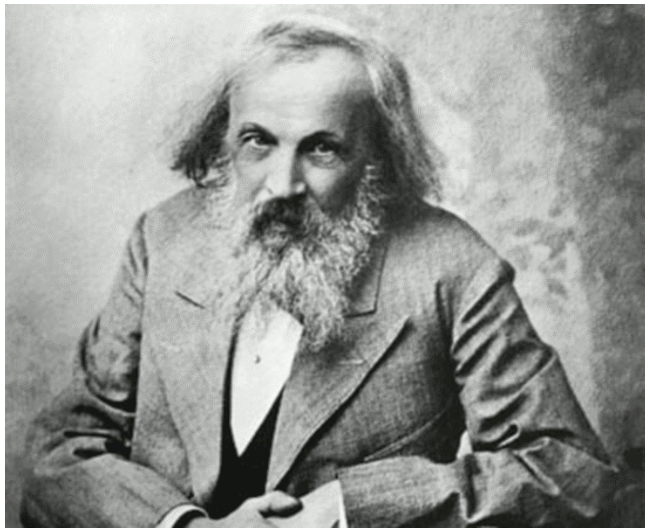
Chemistry:
The Active Power of the Elements

by Michael Kirsch

Dmitri Mendeleev, in his great work, *The Principles of Chemistry*, fundamentally transformed the way man understand the material world around him, by introducing a new concept of fundamentally *chemical*, rather than *physical* principles. Just as the economic value of any product or process depends on the context in which it exists, so too do the physical properties of all materials change: from density to specific heat, from electrical properties to color. Mendeleev went beyond the measurable *physical* properties of the compounds that elements enter into, to discover the periodic ordering of the *chemical* properties of the elements: the chemical transformations they were capable of. Allowing nature to speak for itself, he discovered a unity underlying all of matter, and swept away the foolishness of the alchemists and reductionists.



Dmitri Mendeleev (1834–1907), whose discovery of the periodic ordering of the elements, which provided a universal view of all matter, is left out of today's education, or is shamefully glossed over. Working through his discovery should be required for any student of chemistry.

Setting the Stage

In the middle of the 15th century, Nicholas of Cusa asked what benefit man would gain if weight scales were used to compile the weights of metals, plants, and many other things, in order to measure the unseen in things which cannot be sensed directly.[1]

A fundamental turning point in the process of revealing the lawfulness of the chemical structure of the universe was achieved when, in the 18th century, Antoine Lavoisier subjected the transformations of substances to weight scales. Among the experiments he performed, Lavoisier found that by weighing green powdery copper-carbonate (malachite) before and after heating it in a container of air, the weight of the resulting black substance was less than the original green substance, meaning that something had separated from it. He noticed that a gas was released during the heating, and by funneling it to exit through a tube of the heated vessel, he could measure the quantity of the released gas, carbon dioxide (CO_2). Since the sum of the weights of the new black copper oxide (CuO) and newly formed carbon dioxide gas was equal to the former weight of the copper carbonate originally taken, Lavoisier was led, by this and other demonstrations, to the law of the indestructibility of matter: that in all transformations of compounds of elements into others, matter is not created and does not disappear, but that "the sum of the weights of the substances formed is always equal to the sum of the weights of the substances taken."[2]

Coinciding with this discovery, Lavoisier was able to conduct other investigations which revolutionized the conception of substances altogether. After heating me-

1. Cusa, for example, in his *Idiota de Staticis Experimentis*, proposed to come to the nature of herbs by using weight and taste, rather than taste alone, and to measure the sickness of a man by his blood quality, using its color and weight, rather than using the sense of sight alone; on the basis of the agreement or difference of weights of these substances, the correct dosage of herbs could be given for the correct illness. Among the tasks to be taken up were weighing the amount of water displaced by different submerged metals as a means to measure and determine their non-visual differences, measuring the invisible power of a magnet by how much weight it displaced on a scale, and weighing of seeds taken from different regions to measure the power of the sun at different latitudes.

2. Mendeleev was explicit that all progress in chemistry had been based on Lavoisier's discovery of this fact, since by applying the indestructibility of matter, it was obvious whether one of the resulting substances was being overlooked, as the consequent weight would come out unequal.

tallic mercury in a sealed vessel of air for twelve days, he noted that red scales formed on the mercury. After weighing the remaining air in the vessel, he found that it had decreased in weight by the amount the mercury had increased in weight. He discovered that the mercury had taken in a life-supporting gas, oxygen, forming mercury oxide, and leaving behind another gas in the vessel. This other gas (nitrogen) did not support life, leading to the revolutionary discovery that air is not its own element. Such experiments led him to discover that many compounds could be reduced to simpler states, but only up to a point, writing that if "we associate with the name of elements, or of the principles of substances, the idea of the furthest stage to which analysis can reach, all substances that we have so far found no means to decompose are *elements* for us."

Mendeleev's Concept of the Element

A century later, Mendeleev drew out the implications of the indestructibility of matter further, making more explicit the fact that the subject under investigation was not one of sense perceptible substances, but certain characteristics which *cause* change but are themselves unchanged: "many elements exist under various visible forms while the *intrinsic element* contained in these various forms is something which is not subject to change." Mendeleev spelled out this difference between sensible forms and the true conception of elements in detail.

Making use of charcoal as a case in point, he stated that although the matter making up charcoal is found in organic substances in combination with hydrogen (H), oxygen (O), nitrogen (N), and sulfur (S), "in all these combinations there is no real charcoal, as in the same sense there is no ice in steam. What is found in such combinations is termed 'carbon'—that is, an element common to charcoal, to those substances which can be formed by it, and also to those substances from which it can be obtained." Similarly, carbon appears uncombined with other elements in charcoal, graphite, and diamond, but yet "*the element carbon alone* contained in each *is one and the same*."[3] Carbon dioxide contains carbon, and not charcoal, or graphite, or diamond. Therefore, when iron ore or another metal oxide is burned with charcoal and the heat allows the oxygen from the metallic oxide to combine with the carbon in the charcoal, it is not *charcoal* which is forming a compound with the oxygen of the metal; the material expression of carbon in the newly formed carbon dioxide is incommensurable with that in charcoal.

For Mendeleev, an element was known not by its physical characteristics, but by the chemical transformations it can undergo. He wrote: "Mercury oxide does not contain two simple bodies, a gas and a metal, but two elements, mercury and oxygen, which, when free, are a gas and a metal." The essences, or tranformative potential of elements, are in compounds, rather than any particular state of the element. In this way, the presence of the principle is made primary, or as he wrote, "the composition of a compound is the expression of those transformations of which it is capable." Similarly, there is not oxygen of any one form in oxygen gas, ozone, water, nitric acid, or carbon dioxide, but a principle which is capable of producing all of them, leading to the truth that, "as an element, oxygen possesses a known chemical individuality, and an influence on the properties of those combinations into which it enters."

Mendeleev did not make the transformations of sense perceptible materials the study, but rather *the power to transform*—the invisible principles which characterize and determine possible actions, which are maintained through all the visible changes of compounds. This is further underscored in an 1889 speech, where he referenced this conception:

> Before there was an idea of a primary matter, as to the material world, they adopted the idea of unity in the formative material, because they couldn't resolve any other possible unity to connect the relations of matter. I have discovered through the universe a unity of plan, a unity of forces, and a unity of matter; and the convincing conclusion of modern science compels everyone to admit these kinds of unity. We must explain the individuality we see everywhere. It has been said of old [by Archimedes], "Give a fulcrum, and it will become easy to displace the earth." So also we must say, "Give anything that is individualized, and the apparent diversity will be easily understood." Otherwise, how could unity result in a multitude?[4]

The Principles of Chemistry

As with Kepler's *Mysterium Cosmographicum*, which Kepler, upon its re-publication, decided not to change but only update with footnotes, Mendeleev never changed the presentation of his original 1869 *Principles of Chemistry*, but continuously updated the old version with added footnotes, which by the seventh edition were as long as the original book itself. Mendeleev's faithfulness to his original presentation reveals that he considered the key steps of his breakthrough, as originally presented, to be a correct direction of scientific thought.

For the first nine chapters of *Principles of Chemistry*, Mendeleev investigates the properties of the four elements hydrogen (H), oxygen (O), nitrogen (N), and car-

3. Mendeleev, *Principles of Chemistry*, George Kamensky, trans., New York: Longmans, Green, and Co., 1891.

4. Mendeleev's memorial Faraday Lecture to the Chemical Society in London.

bon (C), and the simple patterns of the way in which other elements combine with them, these compounds serving as *types* for compounds of other elements. For example, the number of atoms of hydrogen which entered into molecules per one atom of another element—be it one, two (as with oxygen in water, H_2O), three (like ammonia, NH_3), or four (with carbon to form methane, CH_4)—made it possible to foretell other compounds these elements could form.

But, it is not possible to foretell all properties from this alone, and in Chapter 10, he turns to a deeper characteristic which leads him to then begin discussing the breakthrough regarding a system of organization of the elements as a whole. He says that there exist among the elements qualitative analogies and relations which are not exhausted by their compounds, but are most distinctly expressed *in the formation of bases, acids, and salts of different types and properties*, and that for a complete study of the nature of the elements, it is especially important to become acquainted with the salts. Certain elements provided extreme examples of the actions that others are capable of performing.

At one end, chlorine provided a unique example. "It forms strong acids with hydrogen and oxygen-acids that give salts, such as common table salt, upon combining with metals."[5] Four elements, fluorine, chlorine, bromine, and iodine, had these same properties of reaction when combining with metals and non-metals. This group was called the halogens ("salt producers", using the Greek word for salt), elements which all gave their compounds specific properties which they alone shared.

Foremost among their properties is the mentioned salt forming *acid oxides*. The acid oxides of bromine and iodine, are similar to chlorine, as hypobromous acid (HOBr) corresponds in its properties with hypochlorous acid (HOCl), both formed by adding pure bromine or chlorine to water. The salts of these acids,[6] such as sodium hypochlorite (NaOCl) both share the same bleaching property and are also both very unstable.

At the other end, Mendeleev then introduced sodium (Na) and its analogues, known as the *alkali metals*, which are characterized by their power to form the most *basic* oxides but no acid oxides. As he wrote later, "…the sodium contained in table salt, NaCl, is the model for elements giving only bases, and not oxygenated acids. In its combination with oxygen, it gives a base, sodium oxide." Sodium has a power of decomposing water easily through its capacity to form the most stable basic oxides. It has such an affinity for oxygen that it is not found naturally, but oxidizes almost immediately when exposed to air. Other unique characteristics of sodium are its power to form salts that are soluble, like sodium sulphate and sodium carbonate.

Other elements also do not appear in a free state, oxidize in air quickly, decompose water, form soluble hydroxides, and form similar salts. These are potassium, lithium, and cesium, known collectively as the "alkali metals."

By means of comparison with the halogens and alkalis, other elements can be considered with regard to these extremities. Some elements approach the alkali metals in capacity of forming salts and not acid compounds, but are not as energetic as akalis. Other elements approach the halogens, but do not have the same energy: in a free state they combine with metals easily, but do not form salts like halogens. Sulfur, phosphorous and arsenic fall here. Then there are elements which are neither like alkali metals or halogens, such as carbon, nitrogen, and oxygen.

Prior to Mendeleev, some had ordered the elements according to their atomic weights,[7] but suffered from faulty pure numerical orderings, and had groups with completely dissimilar elements listed together. Mendeleev did something different:

> Nobody has established any theory of mutual comparison between the atomic weights of unlike elements although it is precisely in connection with these unlike elements that a regular dependence should be pointed out between the properties and the modifications of atomic weights.

He elaborates:

> Everybody understands that in all changes in the properties of simple substances, *something* remains unchanged and that, in the transformation of the elements into compounds, this material something determines the characteristics common to the compounds formed by a given element. In this regard only a nu-

5. "How I discovered the Periodic Law" 1899, in *Mendeleev on the Periodic Law: Selected Writings, 1869 – 1905*, Dover Books on Chemistry, William Jensen, editor, 2005.

6. An acid, saturated with an alkali solution, will release heat, and if evaporated, a solid crystalline substance is yielded. This is called a salt, in the chemical sense, a compound of definite quantities of an acid with an alkali. More generally, a salt is an acid in which hydrogen is replaced by a metal. In this case the hypochlorous acid HOCl, becomes sodium hypochlorite, NaOCl, a salt, where hydrogen (H) is replaced by sodium (Na).

7. Atomic weight can be understood as follows: Forming water chemically, from hydrogen and oxygen gas, reveals that there are about 8 parts oxygen to 1 part hydrogen, by mass. However, Joseph Gay-Lussac had earlier found that two volumes of hydrogen gas combine with one of oxygen to form water; therefore, there are two volumes of hydrogen making up the 1 part to 8 of mass. In other words, there will be two hydrogen atoms for each oxygen atom which make up the water molecule. The atomic weight of the two elements was therefore 1 to 16, oxygen having atomic weight of approximately 16, in relation to hydrogen taken as 1. This measurement is a chemical property, not a physical one: it can be discovered only by chemical processes of combination.

ОПЫТЪ СИСТЕМЫ ЭЛЕМЕНТОВЪ

ОСНОВАННОЙ НА ИХЪ АТОМНОМЪ ВѢСѢ И ХИМИЧЕСКОМЪ СХОДСТВѢ

			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.
H = 1			Cu = 63,4	Ag = 108	Hg = 200
	Be = 9,4	Mg = 24	Zn = 65,2	Cd = 112	
	B = 11	Al = 27,4	? = 68	Ur = 116	Au = 197?
	C = 12	Si = 28	? = 70	Sn = 118	
	N = 14	P = 31	As = 75	Sb = 122	Bi = 210?
	O = 16	S = 32	Se = 79,4	Te = 128?	
	F = 19	Cl = 35	Br = 80	I = 127	
Li = 7	Na = 23	K = 39	Rb = 85,4	Cs = 133	Tl = 204
		Ca = 40	Sr = 87,6	Ba = 137	Pb = 207
		? = 45	Ce = 92		
		?Er = 56	La = 94		
		?Yt = 60	Di = 95		
		?In = 75,6	Th = 118?		

Д. Менделѣевъ

Mendeleev's 1869 periodic table. The relationship between groups of elements that are similar in their chemical activity, and the atomic weights of those elements, gives rise to the periodic relationship expressed in the form of a table by Mendeleev. Each column is a period. Note the question marks for elements that had not yet been observed, but that Mendeleev had hypothesized to exist.

merical value is known, and this is the atomic weight appropriate to the element. The magnitude of the atomic weight, according to the actual, essential nature of the concept, is a quantity which does not refer to the momentary state of a simple substance but rather belongs to a material portion of it—a portion which it has in common with the free simple substance and with all its compounds. The atomic weight does not belong to coal or to diamond but rather to carbon.[8]

Periodic Properties

Mendeleev writes: "The formation of such natural groups as the haloids, the metals of the alkalis…and alkaline earths…furnished *the first opportunity* of comparing the different properties of the elements with their atomic weights."[9]

By comparing the propensity for combination with atomic wieghts, certain powers of transformations became most important. Mendeleev saw that the halogens arrange themselves by their physical properties, such as ease of oxidation and the stability of the oxides they formed, in the same order as they stand in respect to their atomic weights. Their atomic weights are fluorine (F)=19, chlorine (Cl)=35.5, bromine (Br)=80, and iodine (I)=127. Accordingly, iodine acid oxide is more stable than chlorine acid oxide, with iodine having a much greater affinity for oxygen than chlorine. Mendeleev excitedly points out, that bromine, whose atomic weight is nearly halfway between that of chlorine and iodine, also holds an intermediate position with respect to oxide stability. Fluorine, he says, because of chlorine's difficulty in doing so, predictably does not form an oxide at all.

Their relation to hydrogen can also be so compared, only in reverse order. Fluorine has such an affinity with hydrogen that it decomposes water at room temperature, while iodine has an enormous difficulty in combining with hydrogen. Their compounds with hydrogen are therefore likewise arranged according to atomic weight, with hydrogen chloride being the most stable, hydrogen bromide occupying the middle position, and hydrogen iodide the least stable. Other properties corresponded with atomic weight as well: the higher the atomic weight, the higher the specific gravity, vapor density, and melting and boiling points.

The case is similar for the alkali metals, whose atomic weights are lithium (Li)=7, sodium (Na)=23, potassium (K)=39, rubidium (Rb)=85, and cesium (Cs)=133. The chloride salts of lithium and sodium are soluble, but the chloride salts of potassium, rubidium, and cesium are hardly soluble. Thus, the greater the atomic weight, the less soluble is the salt. The variation of properties with the weight even shows itself in the free metallic form of the metals themselves, not just their salts; lithium volatilizes with difficulty, while sodium volatilizes by simple distil-

8. "On the Correlation Between the Properties of the Elements and their Atomic Weights," Mendeleev 1869, in *Mendeleev on the Periodic Law: Selected Writings, 1869–1905*, Dover Books on Chemistry, William Jensen, editor, 2005.

9. "On the Periodic Regularity of the Chemical Elements," Mendeleev 1871, *ibid.*

Period	I	II							Group				III	IV	V	VI	VII	VIII
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo
8	119 Uun																	
		* Lanthanides		57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
		** Actinides		89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

A modern table of the elements, developed as an outgrowth of Mendeleev's periodic ordering. The presentation of this table to chemistry as a given, without developing the process of experimentation and thought that gave rise to Mendeleev's concept, has stunted their creative potential.

lation. Potassium volatilizes yet more easily than sodium, and rubidium and cesium are still more volatile. In other words, ease of volatility increases with atomic weight.[10]

This method thus became a measurement to determine whether a grouping was real (intrinsic to the elements themselves), or merely a false imposition. In an account of an earlier attempt at organization, Mendeleev found that of the characteristic features of alkalis and halogens, *their extreme basic and acid oxides*, formed the extremes of a periodicity of types of basic and acidic properties.

Li 7	Be 9.4	B 11	C 12	N 14	O 16	F 19
Na 23	Mg 24	Al 27.3	Si 28	P 31	S 32	Cl 35.5

For example, moving from the right to the left, in relation to hydrogen, the acidic character lessens. Thus hydrochloric acid (HCl) is a very decided acid of great stability; whereas hydrogen sulfide (H_2S) is a weak acid decomposed by heat, and phosphine (H_3P) has almost no acid properties. In relation to oxygen, the case is inverted: moving from left to right, the oxides, starting with sodium oxide (which is so stable that it only separates with oxygen upon being heated to the temperature of melting iron) decrease in stability.

In addition, the ability of elements to combine in ways similar to hydrogen, oxygen, nitrogen, or carbon, now correlated exactly with this ordering of the atomic weights. The numerical relationships of combination were known as valence numbers. The fluorine and lithium groups (halogens and alkalis) had valence 1, combining like hydrogen. The beryllium and oxygen groups had valence 2, the boron and nitrogen groups valence 3, and the carbon group valence 4. Corresponding members in different rows (such as lithium and sodium) produce the same types of compounds: they possess the same valences.

Such characteristics as these created boundaries which were used in placing the rest of the elements within the ordering system and redefined earlier known laws of chemistry from a higher standpoint. Seeing the correspondence of the atomic weights with such properties as these guided the organization of the system. After these chapters, in which his principle was applied, came the formalization of his periodic law:

> The properties of the elements (and of the simple and compound substances which they form) show a periodic dependence on their atomic weights.... All of the

10. Also, in another group, the "alkaline earth" group—Be, Mg, Ca, Sr, and Ba—the alkaline properties increase with atomic weights, and show themselves in many of their compounds. Ca decomposes water with ease, Mg does with difficulty, and Be not at all.

functions which express the dependency of the properties on the atomic weight may be characterized as periodic functions. At first, the properties of elements change as the atomic weight increases; then they repeat themselves in a new series of elements—a period—with the same regularity as in the preceding series.

Therefore, what defines an element? Is it its material form? No, it is defined by how it is situated in a periodic set of relationships to all others.[11] From that standpoint, it is important to supersede common blunders, which reduce his breakthrough simply to an organization of the elements according to their atomic weights. Others had done that. Mendeleev allowed for these individualities—investigated as characteristics of change, present in the smallest part, which influence any substance dynamically—to define themselves and organize themselves by their unique actions, all in relation to another chief characteristic, atomic weight.

We highlight here the notable fact that just as Cusa had proposed to compare the measurement of the weight of blood with the visible color of the blood, to get at a truth by relating the two, for Mendeleev, it was the relation between, on the one side, these certain characteristic actions, such as the power of their acid and basic oxides, how they combined with other elements—characteristics that formed groups of elements—and, on the other, the invariant of *atomic weight*, which revealed the unique periodicity and presence of a higher principle of organization, one not completed by Mendeleev.[12]

Mendeleyev gave this explanation of the standpoint from which he discovered the periodic law.

> Of the exact nature of matter we have no knowledge. ...We are unable to comprehend matter, force, and the soul in their substance or reality, but are only able to study them in their manifestations in which they are invariably united together, and beyond their inherent indestructibility they also have their tangible, common, peculiar signs or properties which should be studied in every possible aspect. The results of my labors in the study of matter show me two such signs or properties of matter: (1) the mass which occupies space and evinces itself in gravity or more clearly and really in weight, and (2) the individuality expressed in chemical transformations and most clearly formulated in the notion of the chemical elements. In thinking of matter outside any idea of material atoms, it is impossible for me to exclude two questions: How much and what kind of matter? Which qualities correspond to the conceptions of mass and of the chemical elements? There the thought involuntarily arises that there must be some bond of union between mass and the chemical elements; and as the mass of a substance is ultimately expressed (although not absolutely, but only relatively) in the atom, a functional dependence should exist and be discoverable between the individual properties of the elements and their atomic weights.[13]

In Conclusion

In approaching a new, undiscovered principle, the wise thinker, since the days of Nicholas of Cusa, always chooses to let the higher process define itself.[14] Rather than describing a new process by its effects, the human mind must always get "inside" the higher physical process that is being investigated and let it define its own laws; not by what it produces, but by investigating *how* it produces it.

Through the contributions of Cusa, Lavoisier, and Mendeleev to chemistry, we see new dimensions *of characteristics of matter and its actions. We find specifically chemical properties of the elements themselves, distinct from the physical properties of the compounds they enter into. This chemical understanding shed new light on processes of the past—knowing why they occurred as they did—and made it possible to hypothesize new technologies and experiments in the future. Mendeleev opened a new understanding, a new dimension of matter itself, one that forms the basis of much of what has come since: from petroleum refining to photography, from pharmaceuticals to batteries, to the hundreds and thousands of other new chemical compounds developed since his time, and those still to be invented.*

The next dimension of physical chemistry to explore is the domain of electromagnetism.

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11. It may also be noted that while the periodic law showed that "our chemical individuals display a harmonic periodicity of properties, dependent on their masses," Mendeleev made the point later that most periodic functions are continuous, but the one which he discovered is peculiarly made up of discrete jumps, in addition to various lengths of the periods. It is notable that therefore, mass is capable of a non-linear function in that it does not have a continuous relationship to chemistry of matter. It is periodic. As the mass of elements increases discretely, so properties change, and then at another discrete mass change, it cycles back in terms of the properties, but slightly changed.

12. For a more in-depth demonstration of the periodic law, readers are referred to Chapters 15 on that subject in Mendeleev's *Principles of Chemistry*.

13. Chapter 15 of Mendeleev, *Principles of Chemistry*, George Kamensky, trans., New York: Longmans, Green, and Co., 1891.

14. This approach rests on the foundations of the method of modern science, in line with Nicolas of Cusa's approach to the quadrature of the circle, Kepler's and Leibniz's method of dynamics and higher transcendentals, up through Gauss and Riemann's elliptical functions. See Kirsch, "The Calling of Elliptical Functions," *Dynamis* magazine, December 2008, at: http://science.larouchepac.com/publications/dynamis/issues/december08.pdf