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D. I. Mendeleev: Reflecting on His Death in 1907

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1. Introduction

February 2 (January 20 by the Old Style Julian calendar), 2007, marks the 100th anniversary of the death of Dmitrii Ivanovich Mendeleev (1834–1907), most often identified as the Russian chemist who formulated the Periodic Table of Chemical Elements. Already some violence has been done to Mendeleev's memory in reducing him in this fashion, as that is not necessarily how he saw himself. Russian he indubitably was, and proudly so, but he saw himself as more than a chemist, and certainly as someone responsible for much more than merely the Periodic Table—a somewhat unintentional accomplishment of a 35-year-old man in 1869. What we usually commemorate in marking Mendeleev's passing is more often 1869, not 1907. He did not know, as none of us know, when he was going to die, although he certainly suspected that his health was going poorly. Mendeleev lived his life forwards, as we all do, interpreting his past in light of his present. As our present differs from his, we remember him differently than he would have expected.

Mendeleev was fully aware that the Periodic Table was a great achievement; he would have demurred, perhaps, about whether it was *the* great achievement of his lifetime. I propose in this essay to sketch out what Mendeleev himself thought his life meant at those few moments in his last decade when he reflected upon his own mortality. Perhaps surprisingly, we find a man much more concerned about the state of the Russian Empire and his own public service than his contributions to the periodic law, the latter of which he considered to be a bit more unstable than the former. To understand this inversion of our contemporary sensibilities—after all, the Periodic Table hangs in almost every chemistry classroom in the world, while the Russian Empire Mendeleev knew disintegrated most dramatically in the revolution of 1917—we need to consider Mendeleev in the context of the chemistry and the Russia of his own time.[1] Mendeleev's last years were ones of tremendous excitement and change, neither of which were qualities the aging scientist particularly valued.

2. Deathbed Autobiographies

Mendeleev sought to bring his life into focus for historians and biographers on three occasions in the last months of his life. Each of these attempts—much like each of the attempts to refine the Periodic Table during the time he most intensively explored it (1869–1871)—builds on what he had previously assembled and adds or develops a specific feature of his own self-image. They are presented here not in their chronological order, but, somewhat arbitrarily, in order of increasing familiarity with our own current vision of Mendeleev's significance. This was, importantly, neither the first nor the last way Mendeleev saw himself. He quite correctly saw his career as a series of inventions, of created devices meant to bring more order to the chaos and the crumbling systems he saw around him. As he felt his own death approaching, he turned to his greatest invention: himself.

The last of these three autobiographical recreations to be written was an annotated chronology entitled "*Biographical Notes on D. I. Mendeleev*", begun on September 2, 1906, which he noted were "*written entirely by me—D. I. Mendeleev*".[2] Commenting repeatedly to several of his friends and associates that his death was impending, he divided his life into segments of time and recorded the most important incidents in each. In fact, the entry for 1906 included the comment: "*Began to bring books and papers into order—this keeps me very occupied—before death, although I feel fine.*" The method was far from scientific or exhaustive, and the entries tended to get fuller and more detailed in the last fifteen years of his life.

The final article bears many idiosyncracies. One of the most notable features of the biographical notes is how many important events Mendeleev omitted, such as his two-year postdoctoral sojourn in Heidelberg (Germany), where he formed some of his closest (albeit temporary) associations with individuals such as Emil Erlenmeyer, Aleksandr Borodin, and I. M. Sechenov. At the same time, Mendeleev emphasized those parts of his life story that fit the already congealing cliché of how to describe the life of a great scientist: He stressed his provincial origins in far-off Tobol'sk, Siberia, his sickly youth, and his battles with more established figures who failed to appreciate his genius. In all of these duels, of course, whether against geography, nature, or authority, he emerged victorious. His staggering defeats, such as his rejection by the St. Petersburg Academy of Sciences in November 1880, pass without a men-

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tion. In furtherance of this theme, the details of his scientific work are barely mentioned (the years 1869–1871 comprise eleven words, none of them on the Periodic Table), but his orders of merit from the Tsarist state and his foreign travels are lovingly catalogued by the year. The Mendeleev invented here and memorialized by the man himself is one who is lauded by his state for his triumphs over adversity, but less as a scientist than as a public servant devoted to the economic and technological restructuring of Tsarist Russia.

The first autobiographical piece to be written, although one of the last to be read, was a private letter Mendeleev wrote to his erstwhile patron, the Minister of Finances, Sergei Witte, in August 1903. After a real-estate speculation went badly for Mendeleev, he began to reflect on how he would support his family (he still had a wife and two young children at home) if he died. He wrote this letter to Witte, soon to become in 1905 the first Prime Minister of Russia, and had it sealed with instructions to mail it on the event of his death. In September 1906, having outlived his expectations, Mendeleev sent the letter off anyway.[3] This letter had a purpose: it was designed to display before Witte Mendeleev's significance to the Russian state and to shame that state into providing help to his family as a posthumous reward. It was very much a utilitarian document. If the biographical notes were an effort to make historians in the future think well of him as an Imperial civil servant, the letter to Witte was an attempt to make one man in the present think well of him as a protégé.

The letter sketched out three "services" he had provided to motherland and science over his 48-year career (thus fixing the date in 1903). The first fruit of his work was "scientific fame", although Mendeleev did not link this specifically to the Periodic System but measured it entirely through his membership in over fifty foreign and domestic scientific societies and institutions. His second service was to train thousands of students in the principles of science. He concluded: "*My third service to the Motherland is least visible, although it has occupied me from my youngest years to the present. This is the service, the extent of powers and possibility for the growth of Russian industry…*" Here, too, Mendeleev's conception of himself at the end of his life was largely in terms of public service; even his scientific accomplishments were recognized by himself only in terms of prestige, not what we might consider grander epistemological contributions.

So, did Mendeleev, as he pondered his death, *ever* think of himself in terms similar to ours, that is, as the architect of the Periodic Table first and foremost? The answer is yes, but it was in the most private of his three deathbed autobiographies, in a solitary diary entry penned on July 10, 1905, amidst the tumultuous events of the first Russian Revolution.[4] Articulating his objections to a personal attack in the newspapers, he hoped "*that the results of my lifelong efforts remained stable, of course not for centuries, but for a long time and after my approaching death. Only two areas of lifelong efforts do I consider stable myself: my children and my scientific works*". He, of course, hoped for the health of his children, but was much less certain about the stability of his scientific works. He considered these to have four main components: the periodic law, research into the expansion of gases, the understanding of solutions as (non-ionized) associations, and his textbook *The Principles of Chemistry*. Of these four, interestingly, only the first lasts as the basis for Mendeleev's present-day reputation. Despite his hopes, in this single document, for a long-lived diverse reputation in several areas of chemistry and physics, his renown has collapsed into the one single achievement of the Periodic Table.

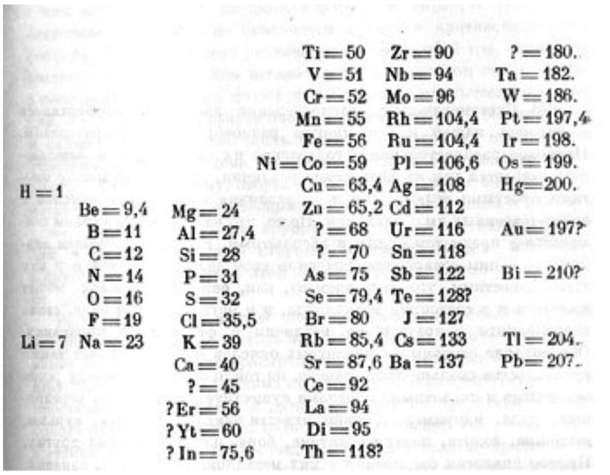
Mendeleev's hopes for how he would be remembered, as articulated differently in his three attempts to control the future, were not fulfilled, or were fulfilled only in the one very important area of the Periodic Table. The oddity of Mendeleev's personal views, in our eyes, leaves two points to be explained: 1) How did Mendeleev's contribution to the Periodic System come to be so closely identified with his entire legacy? 2) Why did he personally believe other aspects of his life to be equally important?

3. Mendeleev's System Becomes Mendeleev's Law

Mendeleev first articulated a Periodic Table in early 1869 in response to the difficulties of organizing the 63 known elements for presentation in the first edition of his textbook, *The Principles of Chemistry*.[5] The first volume of the manuscript offered a detailed account of hydrogen, oxygen, nitrogen, and carbon, as well as the four halogens, leaving over 85 % of the elements to the second volume. It would simply have been impossible for him to provide the same level of detail in the second volume, so he hit upon the idea of organizing some of them into regular families of similar properties, following (to some degree) an accepted idea. While developing this structure for the book, he found that other regular families also existed, and that the order of their atomic weights displayed some regularity. In fact, when the elements were arranged by order of increasing atomic weight, they fell naturally, with a certain *periodicity* (a term he borrowed from the mathematics of periodic functions), into families. He wrote up his first draft of the table on February 17, 1869 (Figure 1).

It is unlikely that Mendeleev understood the generality of his table when he first developed it in February 1869. Had he been cognizant of the implications of the Periodic Table, he would most likely not have relegated the initial presentation of it to the Russian Chemical Society in March 1869 to his friend Nikolai Menshutkin while he went off to inspect cheese-making cooperatives. Over the next months and years, Mendeleev produced a fuller account of the implications of his system, including his first predictions of new elements, culminating in his stunning articulation of the Periodic Table—and the detailed prediction of three yet-undiscovered elements (eka-aluminum, eka-silicon, and eka-boron)—published in *Annales de Chimie et de Physique* in 1872.[6]

The discovery of the eka-elements within fifteen years made the St. Petersburg chemist's reputation internationally, and simultaneously solidified the status of the Periodic Table as more and more like a law of nature. Both the personal and the scientific goals were



			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 = 35,5	Br = 80	J = 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?		

Figure 1. The first published form of Mendeleev's Periodic System, dated February 17, 1869. Source: reference [21].

clearly central for the ambitious young chemist. (Not incidentally, the successful discoveries of the elements tended to award Mendeleev—the only one of the five independent formulators of the Periodic System to make such detailed predictions—either most or all of the credit for the system, as opposed to, say, Lothar Meyer or J. A. R. Newlands.)[7]

The first of these elements to be found was the one to which Mendeleev had paid the least attention in his predictions, eka-aluminum, which was discovered in France in 1875 as gallium by Paul Émile (François) Lecoq de Boisbaudran. Two features of the discovery of gallium make it distinctive among the eka-elements. First, the obvious similarity of this element with eka-aluminum drew substantial attention to Mendeleev's 1871 system. Second, this was the only case among the three where Mendeleev scoured the foreign literature for possible confirmations of his predictions and made the connection himself. In the cases of eka-boron and eka-silicon, intermediaries stepped in, although they extended full credit to Mendeleev.

There was understandable reluctance among contemporaries to accept the two other predictions on the basis of one, possibly lucky, guess. When the second eka-element was discovered in 1879, Mendeleev's case was much more than twice as strong; it seemed as if there really were some deep regularities reflected in his system. This element, scandium (eka-boron), was a rather complicated case, as it was more similar to the rare earths than either of Mendeleev's other two eka-elements, and such elements were very close to each other both in atomic weight and chemical properties and thus proved hard to isolate. This element was discovered among various rare earths by L. F. Nilson of Sweden. In his original publication announcing this (once again) patriotically named element, Nilson made no mention of the correspondence with Mendeleev's eka-boron; Mendeleev, for his part, could not read Swedish and make the connection himself.[8] It was Nilson's countryman, Per Cleve, who did so.[9]

On February 6, 1886, German chemist Clemens Winkler announced his discovery of a new nonmetallic element in a mineral that had been found in the summer of 1885 near his Mining Academy in Freiberg, and, in a somewhat curious pattern, named this element after his native country (germanium).[10] (None of the three chemists knew of the connection with the other two elements when they discovered their own, which makes this coincidence entirely fortuitous.) On February 25, 1886, V. F. Richter, who had once been the St. Petersburg correspondent of the German Chemical Society (and reported on the first announcements of Mendeleev's Periodic Table in 1869), wrote to Winkler of the connection with Mendeleev's prediction. Winkler was immediately enthusiastic. In a telling comment that would reinforce Mendeleev's own evolving views about the physics-like predictive powers of his law, Winkler for a short time considered renaming the element neptunium, because like the planet Neptune it was discovered by a prediction from interpolation. That is, much as Newton's laws were famously confirmed by the independent ascription of perturbations in the orbit of Uranus to a hypothesized Neptune by John Couch Adams of England (1843) and Urbain-Jean-Joseph Le Verrier of France (1846), Mendeleev would later draw on this physical analogy and the power of prediction to defend his periodic law. (The element we know today as neptunium follows a different astronomical analogy.)

So began the rise of the Periodic Table and its close connection to Mendeleev's name. Yet the view of the Periodic Table as the pinnacle of Mendeleev's career—eventually encouraged by the chemist himself—was a retrospective construction. Mendeleev was not concerned in 1869 with establishing a basic law of chemistry. He was concerned with writing a textbook for young chemists at St. Petersburg University. From 1871 on, however, Mendeleev himself would deracinate periodicity and repeatedly reinterpret the periodic law as an emblem of proper science, and claim that he always knew what he had been doing from the start.

By 1871, Mendeleev was convinced that the periodic law was indeed a law; the difficulty now was to develop a sense of what laws meant in the natural sciences. When the stakes were raised, he turned to an obvious exemplar: Newton's three laws of motion and his law of gravitation, which had enabled physicists for a century and a half to describe the motion of celestial bodies with astonishing accuracy. They also allowed scientists to predict (and eventually discover) new planets from aberrations in orbital motion. The Newtonian model became increasingly important over the course of Mendeleev's career. As the discovery of his eka-elements affirmed his confidence (and the confidence of other chemists) in the periodic law, Mendeleev began to elevate the periodic law to a fundamental law like that of Newton.

Mendeleev articulated his Newtonian ambitions in two lectures in England in 1889. The first, "*An Attempt to Apply to Chemistry One of Newton's Laws of Natural Philosophy*", delivered before the Royal Institution on May 31, 1889, directly attempted to connect his work with that of the former President of the Royal Society, opposing the almost universally accepted structure theory with Newtonian dynamics. He treated these themes more abstractly in his Faraday lecture, "*The Periodic Law of Chemical Elements*", read before the same audience on June 4, 1889. Here, Mendeleev did not lecture directly on Newton's laws but on the nature of his own achievement. He chose to emphasize two aspects of chemistry: the communal effort of chemists to establish frameworks for knowledge, and the necessity of adhering to laws to avoid speculation. Both, he implied, were ideals Newton would support. (Newton's distaste for communal work seems to have been unknown to Mendeleev.[11])

In his later years, Mendeleev consistently turned to Newton as his own historical forerunner rather than to a more chemical precursor, such as Antoine Lavoisier (1743–1794). Lavoisier actually seems almost an overdetermined choice for self-modeling; and yet, Mendeleev made very few references to Lavoisier as a model. Instead of selecting an exemplar that would place his periodic law and himself squarely in the chemical tradition, he opted for Newton, a man with interests in optics, alchemy, mechanics, mathematics, theology, and so on, none of which were Mendeleev's strong suits. Why? First, although Lavoisier's importance in the history of science cannot be disputed, much of that reputation was solidified in the centenary commemoration (in the 1890s) of his execution by the Jacobins, while Newton had been a representative genius since the days of Voltaire.[12] Second, much of Newton's fame stemmed from his creation of laws that could make predictions (Halley's comet, Uranus, Neptune). Lavoisier predicted only the results of specific experiments, not the structure of the universe. Mendeleev's own international reputation was heavily based on his prediction of the three eka-elements, making the analogy with Newton appealing.

4. The Two Eclipses of the Periodic System

So Mendeleev, at least in 1890, had come to see his Periodic System as a periodic law that elevated himself into the role of a new Newton for the physical sciences. If that was the case, why did Mendeleev in his final attempts to tally up his achievements in the first years of the 20th century, not vaunt the periodic law as his seminal achievement. There are two answers to this question. First, Mendeleev had left his post at St. Petersburg University in April 1890 and spent the next sixteen-and-a-half years of his life working for the Russian state on practical projects. These, and not his achievements from four decades earlier, were more salient in his mind. Second, Mendeleev had come to feel that the Periodic System, far from being yet more stable as time went on, had become vulnerable to attacks from recent developments in the physical sciences. Mendeleev did not have the benefit of hindsight that we now enjoy; he had to make his own self-evaluations in the midst of what he felt were triumphs in the civil service and defeats in the sciences. It should not surprise us that he considered matters otherwise than we might.

Mendeleev taught his first classes at St. Petersburg University in the 1850s and was a central pillar of the Natural Sciences Faculty there since 1867. From the beginning of his academic career, Mendeleev had carried on consulting in the private sector for the oil industry or for other commercial concerns such as agriculture or chemicals, but fundamentally his home was always at the university. In Imperial Russia, being a professor meant, first and foremost, being a civil servant, and Mendeleev moved rapidly up the ranks to become a consultant for the Ministry of Finances on technical matters almost from the moment he received his post. When Mendeleev left the university in 1890 in the midst of a fight over student rights with the Minister of Popular Enlightenment, he still had plenty of friends and colleagues in other ministries who were happy to make use of his talents. Immediately upon leaving St. Petersburg University, he worked for almost three years on a variant of smokeless gunpowder, dubbed pyrocollodion, for the Russian Navy, a position of tremendous importance in the modernization of the military in the late Tsarist Empire.[13] Mendeleev left his post there before final decisions were made on employing his gunpowder (it was eventually not adopted) to assume an even more important position.

In 1893, Mendeleev was named the Chief Director of the Central Bureau of Weights and Measures, a newly created institution charged with establishing uniformity in Russian weights and measures, and with making first steps in establishing the metric system in the Russian Empire. Under the jurisdiction of the Ministry of Finances, and thus his patron Sergei Witte (the recipient of the second autobiographical note discussed earlier), the post of Chief Director placed Mendeleev the highest he would ever rise to in the Russian bureaucracy. He did his job exceptionally well. He was the author of the 1899 standardization law, the third (and last) in the history of the Russian Empire and the first to allow for the optional use of the metric system, and he established a system of calibration that enabled the rigorous enforcement of measures and prosecution of fraud. He also set up a scientific laboratory to pursue scientific metrology in the Chief Bureau. Metrological affairs during the Soviet period followed the paths set by Mendeleev.[14] As he approached his death, Mendeleev had greater influence over the fate of science and economics in Russia then than he had ever wielded before (Figure 2). He spent most of his biographical notes from autumn 1906 discussing his recent ventures at the Bureau. It made sense that he saw this as his true legacy as he approached death in 1907.

Mendeleev's success as a bureaucrat was balanced by threats to his fundamental beliefs in chemistry. His understanding was heavily conditioned by the periodic law itself. Matter, according to Mendeleev, had three essential properties: it was atomic (each atom was integral); it was immutable (each specific element had fixed mass and could not become any other element); and each element possessed a specified valency. Thus, each element in the system was placed as an atomic individual (in the literal sense of being without divisions), according to its mass, in a peri-

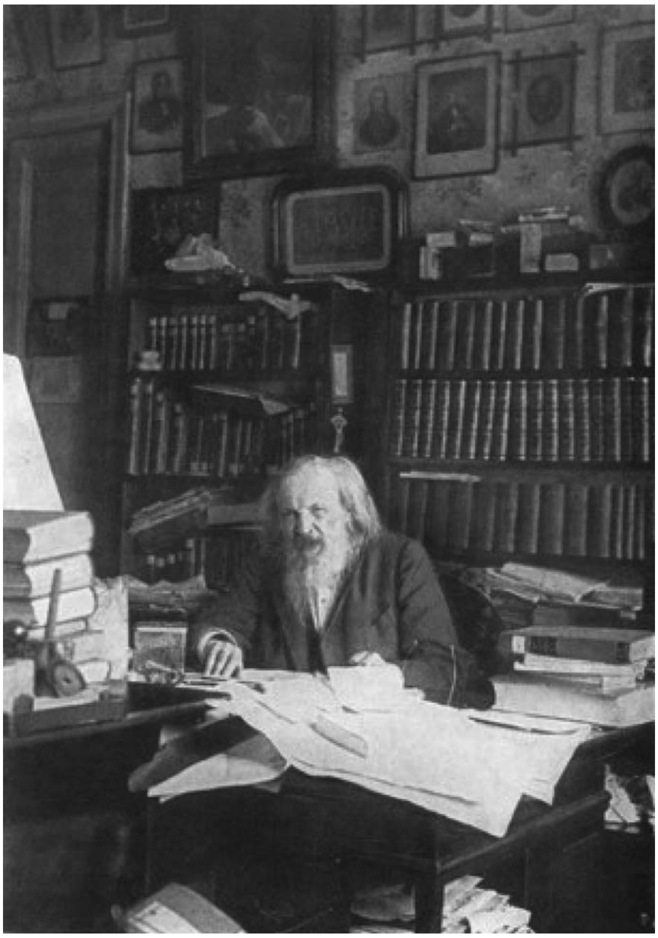


Figure 2. Mendeleev in his home office, located adjacent to the Chief Bureau of Weights and Measures, 1904. Source: reference [22].

odic relation marked by a recurrence of valency. Mendeleev considered these three properties to be of a piece; they were simply what it meant to be a chemical element. From 1894, a new phenomenon had emerged to assault directly each of these qualities of matter, and threatened both the borders of chemical knowledge and the stability of the entire discipline.

The man who had earned international fame by predicting the properties of empty spaces in his Periodic System was taken by surprise in 1894 by William Ramsay's announcement of a new chemical element, dubbed argon—the inert one. While he had greeted the validating discoveries of gallium, scandium, and germanium with pleasure, argon was the first announced element that had no empty space for it in the Periodic System. It had a measured atomic weight of 40, which would place it between chlorine and potassium, and it seemed to be completely unable to bond with other elements. Mendeleev immediately telegrammed Ramsay (in French): "*Delighted at the discovery of argon. Think molecules contain three nitrogen bound together by heat.*"[15] He resisted a novel discovery in chemistry that could be interpreted as violating his periodic law. The threat was not just in Mendeleev's head. After reviewing the properties of the inert gases discovered soon after argon, an American chemist remarked: "*The appearance of so many new elements at one time will no doubt prove embarrassing with the present arrangement of the Periodic System, and attempts will probably be made to rearrange the system to conform to these new discoveries.*"[16]

Mendeleev soon changed his attitude to the element. In 1903, he became a proud partisan of the idea that the inert gases should be considered a zero-valency zero group, to be placed on the far left of the Periodic System (and not the far right, as in modern representations; see Figure 3). In this way, he argued, the system would be organized from least reactive (the inert gases) to most reactive (the halogens).

One sees here that Mendeleev proved able to accommodate the inert gases fairly easily. Radioactivity was another matter altogether. In 1896, in an effort to demonstrate that the phenomena of X-rays (discovered by Wilhelm Conrad Röntgen the year before) were related to fluorescence, French physicist Henri Becquerel undertook a series of experiments on uranium. By accident, he discovered that uranium would cloud photographic plates; a series of further experiments led him to conclude that uranium spontaneously emitted energy. In 1898, Pierre and Marie Curie, in their Paris laboratory, discovered the new elements polonium and radium, which emitted energy of extreme intensity—dubbed radioactivity by Marie. Radioactivity fast became one of the most vigorous fields of research in the physical sciences.

Mendeleev's most salient introduction to radioactivity, and the genesis of most of his hostile views of the phenomenon, was his visit to the Curies' laboratory in Paris in 1902. In accordance with his conservative orientation, Mendeleev preferred innovation when it was built on longstanding tradition, such as the Periodic System. He remarked to a friend: "*Tell me, please, are there a lot of radium salts in the whole earth? A couple of grams! And on such shaky foundations they want to destroy all our usual conceptions of the nature of substance!*"[17] One of the conceptions that would be destabilized was the immutability of the elements, his conviction that elements could not transmute into each other—a modern alchemy.

For Mendeleev, mass was not merely a secondary characteristic of an element's properties as, say, its crystalline structure; rather, it constituted the very identity of an atom. It was how one knew an oxygen atom to be different from a cobalt atom: mass was the most fundamental discriminator. This view stands in sharp contrast to today's understanding of matter, where each atom is composed of a definite number of protons, neutrons, and electrons, and

Series	Zero Group	Group I	Group II	Group III	Group IV	Group V	Group VI	Group VII	Group VIII
0	x								
1	y	Hydrogen H=1·008							
2	Helium He=4·0	Lithium Li=7·03	Beryllium Be=9·1	Boron B=11·0	Carbon C=12·0	Nitrogen N=14·04	Oxygen O=16·00	Fluorine F=19·0	
3	Neon Ne=19·9	Sodium Na=23·05	Magnesium Mg=24·1	Aluminium Al=27·0	Silicon Si=28·4	Phosphorus P=31·0	Sulphur S=32·06	Chlorine Cl=35·45	
4	Argon Ar=38	Potassium K=39·1	Calcium Ca=40·1	Scandium Sc=44·1	Titanium Ti=48·1	Vanadium V=51·4	Chromium Cr=52·1	Manganese Mn=55·0	Iron Fe=55·9, Cobalt Co=59, Nickel Ni=59 (Cu)
5		Copper Cu=63·6	Zinc Zn=65·4	Gallium Ga=70·0	Germanium Ge=72·3	Arsenic As=75·0	Selenium Se=79	Bromine Br=79·95	
6	Krypton Kr=81·8	Rubidium Rb=85·4	Strontium Sr=87·6	Yttrium Y=89·0	Zirconium Zr=90·6	Niobium Nb=94·0	Molybdenum Mo=96·0	—	Ruthenium Ru=101·7, Rhodium Rh=103·0, Palladium Pd=106·5 (Ag)
7		Silver Ag=107·9	Cadmium Cd=112·4	Indium In=114·0	Tin Sn=119·0	Antimony Sb=120·0	Tellurium Te=127	Iodine I=127	
8	Xenon Xe=128	Cæsium Cs=132·9	Barium Ba=137·4	Lanthanum La=139	Cerium Ce=140	—	—		— — — (—)
9		—	—		—	—	—	—	
10	—	—	—	Ytterbium Yb=173	—	Tantalum Ta=183	Tungsten W=184	—	Osmium Os=191, Iridium Ir=193, Platinum Pt=194·9 (Au)
11		Gold Au=197·2	Mercury Hg=200·0	Thallium Tl=204·1	Lead Pb=206·9	Bismuth Bi=208	—	—	
12	—	—	Radium Rd=224	—	Thorium Th=232	—	Uranium U=239		

Figure 3. Mendeleev's revised Periodic System with the chemical ether labeled *x* in the box at the upper left. Source: reference [23].

any given proton in a cobalt atom is identical to any in an oxygen atom, the latter being defined as any atom with eight of these protons in its nucleus. In other words, Mendeleev firmly rejected any notion that atoms were composite. If radioactive elements were emitting subatomic particles, then that implied composite structure, and Mendeleev was accordingly alarmed. The discovery of the electron in 1897 by J. J. Thomson warned for a third time that changes were imminent.

Mendeleev could not let such transgressions against his fundamental conception of matter and, even more importantly, his periodic law pass unanswered. Interpreting the situation in fin de siècle physical sciences as chemistry under attack by superstition and sloppy reasoning, and exasperated by what he interpreted as people letting their irrational preferences dissuade them from proper scientific method, Mendeleev undertook a chemical interpretation of the luminiferous ether that would harness the inert gases to stave off the dangers of radioactivity and the electron. The ether is in poor repute today, having famously been declared superfluous in 1905 in Albert Einstein's special theory of relativity. Mendeleev was never aware of this development, and the ether was one of the most universally acknowledged constituents of the natural world. It was only reasonable that he would turn to this most stable of concepts to defend against his feared instability.

In 1901, Mendeleev was approached by the editors of a new journal, the *Herald and Library of Self-Education*, to write an article on the state of contemporary science for the first issue. This new magazine was the perfect venue to work out his views on the ether. The essence of Mendeleev's project on the ether was to locate it in the Periodic System of Elements—as a noble gas—and then use interpolation techniques to predict its necessary properties, just like the prediction of the three eka-elements in 1871.

He began with the group of inert gases, elevating what was once the albatross of chemical inactivity to a virtue. Ether was to be the lightest element, and at the top of the zero group (above another postulated element, coronium). Mendeleev could now intuit some of its properties:

*Thus **the world ether can be conceived**, like helium and argon, **as incapable of chemical combination**…. When we recognize the ether as a gas this means, above all, that we strive to relate its concept with the ordinary, real concept of the states of matter: gas, liquid, and solid…. If ether is a gas, this means that it is ponderable, it has its own weight. We must ascribe to this if we are not to discard on its behalf the entire conception of the natural sciences which takes its origin from Galileo, Newton, and Lavoisier. But if ether has such a highly developed power of penetration that it goes through all envelopes, then it is impossible to think about experimentally finding its mass in a given quantity of other bodies, or the weight of its specific volume under given conditions, and thus one should speak not of the imponderable ether, but of the impossibility of weighing it.*[18]

Although unweighable, the weight of the ether could be determined using the periodic law. The periodic law only gave an upper cap for what element x, in row 0 and group 0, should weigh ($x \leq 0.17$; with hydrogen H = 1). To find a more exact prediction, he invoked physics, specifically the kinetic theory of gases, computing what the average weight must be for the gas to escape planetary atmospheres. Upon performing a simple calculation using Newton's law of gravitation, Mendeleev argued that x had to be less than 0.038 to escape the earth's atmosphere and less than 0.000013 to escape the sun's atmosphere. He then scaled up to a larger star, γ Virginis, which had a mass 32.7-times greater than that of the sun. His final result was $0.00000096 > x > 0.000000000053$. Interestingly, even though mass can be canceled out of all the escape velocity equations, he did not make the simplification in order to make the calculation more visualizable. He finally calculated that the ether must weigh nearly one-millionth of an atom of hydrogen, and must move at about 2250 kilometers per second. This ether penetrated everything and produced observable effects when it interacted slightly with elements.[19]

Mendeleev assimilated this project for a chemical ether seamlessly with his new self-presentation as a disciple of Sir Isaac Newton. In the article on chemical ether, he added as a brief footnote: "*I would like preliminarily to call it "newtonium"—in honor of the immortal Newton*." In an early draft, scrawled illegibly on both sides of a flimsy scrap of paper, he emphasized this Newtonian aspect even more, concluding: *"[The ether is] the lightest elementary gas which penetrates everything (row 0, group 0), which I would like to preliminarily call newtonium, since the thoughts of Newton penetrate all parts of mechanics, physics, and chemistry.*"[20]

How was this to explain radioactivity and the electron? Mendeleev noted that the chiefly radioactive elements (uranium, thorium, radium, etc.) were the heaviest ones, and thus they must attract a large proportion of lighter matter, just as the sun attracted planets and cosmic dust. Naturally, uranium would be surrounded by a great cloud of attracted ether that dissolved and intercalated with the uranium mass itself. At some critical point, too much ether penetrated the uranium and certain chemical processes, of whose exact nature we were ignorant, caused quantities of ether to be ejected from the sample. Radioactive energy was just the reaction energy produced by the minute and highly diffusive ether. Ether atoms, and not a decayed part of the primary atom, were ejected. There was no transmutation, no primary matter from which all elements were constructed, and the periodic law was preserved.

Needless to say, despite an early flourishing of interest in Mendeleev's theory, the chemical ether did not catch on. By 1906, radioactivity had become so entrenched as a cornerstone of modern atomic theory, that Mendeleev silently retreated, invoking his pet project no more. No wonder that when it came time to think of his legacy, he shied away from the Periodic System—it was not "stable", the word he used in 1905 about his scientific achievements, and his most recent venture in it had been a bit embarrassing. He looked to recent glories and not past glories; and this meant Mendeleev the civil servant.

5. Conclusion: Looking Forward

Mendeleev would certainly have been delighted that his name is still spoken of by chemists a century after his death, even if this might have struck him as unexpected. He did not expect his name would necessarily live in chemistry for a long time. He cast his bets, rather, on the development of the Russian Empire into an industrial capitalist nation state. Given how both Russia and chemistry developed in the century since his death, one can safely say that Mendeleev's predictive powers were not as sharp as they had been in 1871, when he forecast the properties of his eka-elements.

Yet the story narrated here does offer us some insight into how we today might use commemorative dates to deepen our understanding not only of the historical context of these prominent figures in the history of science, but also of their science. It is a truism that no one can predict what science will become in the future, and the hopes of an individual for the legacy of an individual scientific discovery are weak. Mendeleev's case shows us, 100 years after his death, that even the past is not so easy to discern from the vantage point of one's late career.

We tend to see the biographies of great figures in light of their highest points. In that sense, what we commemorate this year with the centenary of Mendeleev's death is not that date but the legacy of 1869–1871, as marked by the lifespan of the formulator of the Periodic System of Chemical Elements. However, individuals' lives do not rise monotonically, and often their careers appear to be at a downswing at the very moment death comes to them. So by all means, let us celebrate the mind and achievements of D. I. Mendeleev; but let us also remember the person behind that name, the scientist, bureaucrat, and father who died believing that he had begun to put his affairs in order.

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[1] For a fuller analysis of Mendeleev's biography, with further documentation on the topics addressed here, see: M. D. Gordin, *A Well-Ordered Thing: Dmitrii Mendeleev and the Shadow of the Periodic Table*, Basic Books, New York, **2004**.

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[3] Reproduced in S. A. Shchukarev and S. N. Valk, *Arkhiv D. I. Mendeleeva, t. 1: Avtobiograficheskie Materialy, Sbornik Dokumentov*, Izd. Leningradskogo gosudarstvennogo universiteta im. A. A. Zhdanova, Leningrad, **1951**, 31—33.

[4] Reproduced in S. A. Shchukarev and S. N. Valk, *Arkhiv D. I. Mendeleeva, t. 1: Avtobiograficheskie Materialy, Sbornik Dokumentov*, Izd. Leningradskogo gosudarstvennogo universiteta im. A. A. Zhdanova, Leningrad, **1951**, 34–36.

[5] For details, see: M. D. Gordin, *A Well-Ordered Thing: Dmitrii Mendeleev and the Shadow of the Periodic Table*, Basic Books, New York, **2004**, chap. 2. See also: I. S. Dmitriev, *Voprosy istorii estestvoznaniia i tekhniki*. **2001**, *no. 1*, 31–82.

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[19] D. I. Mendeleev, *Vestnik i Biblioteka Samoobrazovaniia*, **1903**, *nos. 1–4*, 165–167.
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