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MAKING NEWTONS: MENDELEEV, METROLOGY, AND THE CHEMICAL ETHER

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Oh you, whom the fatherland
Expects out of its depths
And wishes to see those,
Like it summons from other lands.
Oh your days are blessed!
Dare now to be encouraged
By your zealousness to show,
That to its very own Platos
And the quick reason of Newtons
The Russian land can give birth.

M. V. Lomonosov[1]

IN 1901, Russian chemist Dmitrii Ivanovich Mendeleev (1834-1907), referring to this passage by eighteenth-century natural philosopher and poet Mikhail Lomonosov that Russia would in the future have its own Platos and Newtons, stated that Russia should abandon its search for Platos and redouble its efforts in the production of 'Newtons'. This statement is usually read as a testimony to Mendeleev's intense scientism, but such interpretations, while partially correct, neglect the comment's immediate textual context. Right afterwards Mendeleev added: 'But Plato and Newton were teachers of youth, and thus considering Russian education, above all one must concern oneself with teachers'.[2] Mendeleev's concerns are for the reform of Russian education; his desire to 'make Newtons', as well as his own self-fashioning as the successor of Newton's scientific method and the fruit of Lomonsov's plea, thus hinge on his general views on social reform.[3]

Besides his formulation of the periodic table, Mendeleev also pioneered reforms in economics, military policy, popular education, and trade, to name just a few. His educational reform was one of the final projects he undertook, and it is exemplary of his general view of society and his plans for the gradual reform of Russia into a more 'advanced' European state. The first step to improving education was to ban general examinations, since they only took away from class time, encouraged rote memorization, and discouraged individual innovation. This was no way to make Newtons. Instead, much more attention should be paid to the training of teachers from the elementary school level through university, whose increased competence would take up the slack generated by the elimination of examinations. The problem, in all of

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Mendeleev's pedagogical writings, was that teachers were inadequately trained:

> Above all it is necessary to see clearly that the demand for the special preparation both of professors and even of gymnasium teachers is no less necessary than the preparation of all other specialists: artillery experts, engineers, technicians of all types, agronomists and so forth; because pedagogical specialty. . . demands not only its own experience but also continuing meditation, and it is no less necessary for the general life of the state than the others.[4]

The final stage of this educational reform, a stage that never ends, was to send inspectors, drawn from the ranks of the most experienced teachers, out to all the schools of the country to ensure equivalent levels of teaching in all corners of the Empire.[5]

This plan for reform appears to cohere incongruously with the thought of the man who designed the periodic table of the elements and formulated one of the most far-reaching protectionist tariffs in the history of Europe. I introduce this educational reform in brief, however, to illustrate a more general point about just how *coherent* Mendeleev's conceptions of society and science were.[6] When he came up with this plan for the reform of popular education, Mendeleev had been serving as Director of the Chief Bureau of Weights and Measures for almost ten years. There he worked on the standardization of imperial measures and the eventual universal introduction of the metric system. To truly understand what Mendeleev meant by making Newtons (the people), we need to explore his metrological activities—the making of the other kind of Newtons (the units of force). An exploration of Mendeleev's metric reform will not only cast light on the far-reaching resonances in all areas of his social thought, it will also allow us to better understand Mendeleev's hostile reception of radioactivity and the transmutation of elements and his proposal of a chemical ether to be classified in the periodic table of the elements. Metrology—the science of measurement—was not just used by Mendeleev to make measurement standards, it was how he set standards everywhere.[7]

I will begin by exploring the 'order of things' which Mendeleev imposed on the natural world in the form of his 1902 advocacy of the existence of a chemical form of the luminiferous ether. By first examining the apparent statics of his philosophy of nature, we will then see how the dynamics of his metric reform operated during his tenure as Director of the Chief Bureau of Weights and Measures. Finally, we will be able to see how the two are linked in a web of metrology, and how the same concepts were used by Mendeleev to propose novel and robust unifying principles in other realms.[8]

PONDERING THE IMPONDERABLE: THE CHEMICAL ETHER AND PERIODIC ORDER

In the early twentieth century the idea of an imponderable luminiferous ether that served as the substrate for Maxwell's equations was alive and well. In the years before and after Maxwell, many physicists tried their hand at establishing a physical model for the ether: incompressible, solid, liquid, rotationally invariant, metallic, or whatever. The models, however, were almost exclusively *physical*: they all concerned the mechanics of how the ether operated, and paid little or no attention to the substance that composed it. The exception to this was Mendeleev's model of the chemical ether, proposed in 1902 and translated into English in 1904.[9] Scientifically, the work reflects an almost complete obliviousness on Mendeleev's part to the extensive mathematical and physical requirements of the ether that were being developed in the West, and especially in England.[10] But mathematics was not important for Mendeleev here; he was not after equations and structure, he was after substance.

The essence of the ether project was to locate the ether in the periodic table of the elements and then use interpolation techniques to predict some of its necessary properties according to the periodic law—the same tactic that had led Mendeleev to predict accurately three undiscovered elements, establishing his international fame.[11] Metrology enters his ether project in two ways: epistemologically and metaphysically. The epistemological point is rather straightforward. Typical descriptions of the ether in Mendeleev's time described it as 'imponderable', as having no weight. For Mendeleev the idea of a substance not having weight was ridiculous. The only way we can know matter is by the set of measurable properties that identify it.[12] This is not surprising from a man who organized a table of elements according to the one variable measurable property recognized in all elements at that time: atomic weight. So if the ether were to exist for Mendeleev, not only must it have mass (for it must be made of something), but it must have a *defined* weight and could thus be located in the periodic table.

Mendeleev conceived of the ether as a gas—namely a noble gas. The first inert gas to be discovered was argon, several years after Mendeleev announced his periodic law. Since Mendeleev could not find a place in his table for an element with no valence, he thought that argon must be a compound like triply-bonded nitrogen, N_3. The eventual confirmation of the elemental status of argon and the discovery of other inert gases like helium, neon, and xenon led Mendeleev to incorporate them into his table as a 0-group, preceding the alkali metals on the left side of the table.[13] Not only did he eventually come to accept the noble gases as a group, but he came to see them as a route to systematizing the ether. Ether was to be understood as the lightest element, lighter than hydrogen, and at the top of the 0-group (above another postulated element, coronium, which served as a stand-in for interpolation).[14] (See Figure 1.) This postulation of the place of the ether led him to some of its properties:

> Hence *the ether may be said to be a gas, like helium or argon, incapable of chemical combination.* . . . The recognition of the ether as a gas, signifies that it belongs to the category of the ordinary physical states of matter, gaseous, liquid, and solid. It does not require the recognition of a peculiar fourth state beyond the human understanding (Crookes). All mystical, spiritual ideas about the ether disappear. In calling ether a gas,

> we understand a 'fluid' in the widest sense; an elastic fluid having no cohesion between its parts. Furthermore, if ether be a gas, it has weight; this is indisputable, unless the whole essence of natural science, from the days of Galileo, Newton, and Lavoisier, be discarded for its sake. But since ether possesses so great a penetrative power that it passes through every envelope, it is, of course, impossible to experimentally determine its mass in a given amount of other substances, or the weight of a given volume of ether. We ought, therefore, not to speak of the imponderability of the ether, but only of the impossibility of weighing it.[15]

The conclusion of this passage does not contradict Mendeleev's epistemological worries about the mass of the ether. While the ether cannot be weighed, it does have weight, and that weight can be determined–but not experimentally. The way to determine the weight of the ether, then, was via the periodic law, where the ether had a special place with specific properties. By interpolation, Mendeleev calculated that the ether must weigh nearly one-millionth of an atom of hydrogen, and must move at about 2,250 kilometers per second. This ether penetrates everything, and thus when it interacts slightly with elements, it should produce observable effects.[16]

These effects are the real reason that Mendeleev felt the need to propose this argument. Mendeleev, as we saw, could not allow the idea that there was a substance in the universe that had no mass. More importantly, there had to be absolutely no possibility of the transmutation of elements. For Mendeleev,

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	Caesium 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		

Fig. 1. Mendeleev's periodic table with the chemical ether. Note that the 0-group of inert gases is on the left of the table rather than the right. For the purposes of calculation, the ether is the box labeled x, and the element below it, y, is coronium, introduced for the purposes of calculation. D. Mendeléef, *An Attempt Towards a Chemical Conception of the Ether*, tr. G. Kamensky, (London: Longmans, Green, and Co., 1904), p. 26.

elements were unitary individuals that could not be transformed into each other, as other chemists like William Prout–who believed all elements were constructed from the same primary substance–had postulated. Unfortunately for Mendeleev's conception, upon which the idea of the periodic table was built, the emerging field of radioactivity seemed to demonstrate that elements were capable of transmuting, or at least that pure elements were 'emitting' some substance from within themselves (thus changing their atomic weight and transmuting).[17] The chemical ether was Mendeleev's elaborate attempt to explain away the effects of radium, which he himself had observed in the Curies' laboratory in Paris. Instead, Mendeleev argued, one must note that the chief radioactive elements (uranium, thorium, radium, etc.) are heavy ones, and thus they must attract a large proportion of lighter matter, just as the sun attracts planets and cosmic dust. Naturally, then, uranium would attract a great deal of the ether, and thus be surrounded by a cloud of it, which begins to dissolve and intercalate with the uranium mass itself. At some critical point, too much ether penetrates the uranium and certain chemical processes, of whose exact nature we are ignorant, cause quantities of ether to be ejected from the sample. The radioactive energy is just the reaction energy produced by the minute and highly diffusive ether. What is ejected is the ether, and not a 'decayed part' of the primary atom, its almost infinitesimal lightness explained why the 'decay products' were not yet weighed. Thus there is no transmutation, no primary matter from which all elements are constructed, and the periodic table is preserved in its epistemological integrity.[18]

There have been several philosophical attempts to try to explain Mendeleev's hostility to transmutation of the elements with reference to an epistemological system. I do not wish to explore these in this paper, since that would take the argument too far afield. They are, however, crucial to a complete picture of Mendeleev's thought and need to be accounted for in a fuller exposition.[19] Mendeleev's resistance to transmutation may be difficult to trace philosophically, but I will propose later that the ether served as a mechanism for Mendeleev to avoid such a possibility, and may provide an additional window to understanding this hostility. Crucially, it allowed him to maintain the universality of atomic matter without capitulating to a primary substance as a building block, and it also gave him a material means for explaining how gravity and electricity could transmit their actions at a distance—all the while saving the periodic law.[20]

We can take this explanation further, I will argue schematically, by viewing Mendeleev's epistemology as fundamentally metrological; measurement is not used in the sense of the Comteans, who argued that only that which is measurable can be described, but in the sense of metrology as defining order. Mendeleev saw the chemical ether as a way of re-establishing the order to the periodic table that mainstream interpretations of radium were threatening to destroy. As he himself put it: 'In endeavouring to clothe the conception of "ether" with a chemical dress, and so to render it an actual, real possibility in harmony with the purely realistic periodic law, I think I am serving the cause of unity in natural philosophy.'[21] The chemical ether was meant to unify the

disparate and distinct elements of his periodic table. A large part of this commitment stemmed from his desire that there be a defined order of things and a defined set of properties for each place in the order: the periodic law (in Mendeleev's later years) was not just a *representation* of how nature worked; it was the *ontological principle* of nature's organization itself, derived through the epistemological principle of metrology.

The first step to specifying this underlying principle of order is to ask what Mendeleev was doing elsewhere when he formulated the principle of the chemical ether. When he wrote his pamphlet on the ether in 1902, he had been working for nine years as the first Director of the newly established Chief Bureau of Weights and Measures, transforming the organization from a mere 'Depot' where standards were kept to a major metrological laboratory with divisions all over Russia He was also in the midst of instituting a reform designed to convert the Russian empire gradually to the metric system, the first stage of which had been passed in 1899 and came into effect on 1 January 1900. This position was more than just a job for Mendeleev. Many who recollect him from this period speak of how much he valued his work at the Chief Bureau and how he managed to integrate independent scientific research into the daily life of metrology.[22] In fact, Mendeleev also managed to do the reverse in integrating metrology as an epistemic concept into his scientific research, especially that of the search for the chemical ether:

> The working out of methods of exact weighing has important significance not only for the direct goals of metrology (for the verification of weights), but also for the resolution of many basic tasks of the natural sciences, for example, the question of the nature of the force of gravity, thus in explaining gravity by fluctuations of the interplanetary (luminiferous) ether it is possible to propose a small change of weight under the transition from the gaseous form of existence into a liquid and back.[23]

In his longest formal statement of the scientific method we can also see the enormous role that metrology was meant to play in science as an order-generating principle:

> The investigation of a substance or a natural phenomenon consists: (a) in determining the relation of the object under examination to that which is already known, either from previous researches, or from experiment, or from the knowledge of the common surrounds of life—that is, in determining and expressing the quality of the unknown by the aid of that which is known; (b) in measuring all that which can be subjected to measurement, and thereby indicating the quantitative relation of that under investigation to that which is already known. . .; (c) in determining the position held by the object under investigation in the system of known objects. . .; (d) in determining, from the quantities which have been measured, the empirical (visible) dependence (function, or 'law,' as it is sometimes termed) of variable factors. . . . It is manifest that it is only possible to carry out these investigations when we have taken as a basis something which is

> incontestable and self-evident to our understanding; such, for instance, as number, time, space, matter, form, motion, or mass. Hence it follows that in the investigation of anything, there always remains something which is accepted without investigation, or admitted as a known and recognized factor; the axioms of geometry may be taken as an example.[24]

Given the preponderance of both order and measurement in his system, we can see that the regularity of nature and its ability to be subjected to organization on the basis of metrics is another such principle which must be accepted *a priori.*

This provides an argument, then, for viewing Mendeleev's ether as an essential component in an episteme of order that was being threatened from within. If we explore the more 'bureaucratic' aspects of Mendeleev's metrology, we will discover that under this apparently static tabular organization of order is a dynamic circulation of standards and a flowing movement of disciplinary standardization.[25] This claim will, in turn, expand our understanding of what was at stake for Mendeleev in his insistence on the chemical ether.

Measure of All the Russias: Mendeleev and the Metric Reform

When Mendeleev became Director of the Chief Bureau of Weights and Measures in 1893, he had just left an extraordinarily long term of service at St. Petersburg University. He found that Russia was no further along in standardizing weights and measures or in introducing the metric system than it had been early in the nineteenth century, when the moves for the introduction of more 'rational' units began to take place. Although there had been intense concern with the standardization of weights and measures in Russia going back to the medieval period, it was not until 1797, early in the reign of Paul I, that the first Empire-wide law on the standardization of weights and measures was proclaimed. The second such law, which standardized the Russian units of measurement—the *sazhen, arshin,* and pound (*funt*)—and related them to the British units of measurement (a *sazhen* is seven British feet exactly), was passed in 1835, during the period of codification and standardization under 'reactionary' Tsar Nicholas I. The third law, planned and written largely by Mendeleev, and passed on 4 (16) June 1899, provided for the use of the metric system on an optional basis, and the standardization of all Russian units with respect to the metric system (and not the British one, as earlier).[26]

Mendeleev had publicly advocated introducing the metric system into Russia since 1867, joining the ranks of several less-prominent scientists. Thus the government's selection of Mendeleev to head the Chief Bureau was not arbitrary; it was, rather, a specific choice of a man determined to change the old Russian units. In his first statement on the metric system on 28 December 1867, Mendeleev argued for the metric system as a means of international scientific unification, one which was easy to work with because of the decimal system, which had exact exemplars, which would serve to standardize various

electrical and mechanical international systems (like the railroad), and which was 'best suited to universal distribution.'[27] Besides orchestrating the 1899 reform, Mendeleev also worked to restructure the Bureau of Weights and Measures from a simple Depot into a sophisticated laboratory-style institution concerned with various aspects of metrology and standardization.[28]

As has been well-documented elsewhere, the metric system faced extreme political reaction everywhere its introduction was attempted—including, especially, its birthplace France.[29] Russia's involvement in the internationalization of the metric system had been prominent even before Mendeleev took the helm, but this interest failed to result in any progress towards domestic adoption. In 1869 the St. Petersburg Academy of Sciences (which did not include Mendeleev) sent a communication to the Paris Academy of Sciences in which they proposed that efforts be made for the establishment of an international metric system. On 8 August 1870, after an initially hostile reception by French scientists, who did not want other nations meddling in French units, a commission was set up to establish internationally reliable units for the meter and kilogram, which were stored in Paris. In 1889 Russian delegates attended an international conference in France, signed an agreement committing to eventual conversion to the metric system, and then took home meter #28 and kilogram #12 from the collection of prototypes. The law of 1899 was seen as the partial fulfillment of this agreement.[30] The complete and obligatory adoption of the metric system did not take place until the Soviet state took control of weights and measures, instituting conversion in 1918 (prompted by ammunition, transportation, and supply failures during World War I due to faulty standardization).[31]

Well before the 1899 ordinance started Russia on the official path of metric conversion, from the moment Mendeleev took control of the Chief Bureau, he began to work out a metric reform. In fact, most of the major actions taken during his tenure were all components of this highly articulated vision of how the metric reform should progress in order for it to succeed.[32] I will now explore this program in detail, but I would like to emphasize from the start that most of what I will be discussing was Mendeleev's vision for how a metric reform should progress. As we shall see, Mendeleev's ideal was quite different from the resultant 1899 law. But Mendeleev's vision is crucial for an adequate understanding of its extremely general shared presuppositions with his chemical ether project.

Mendeleev firmly believed the introduction of the system in Russia was an inevitability. The nature of his job, he felt, was to make sure that it happened smoothly and that the system actually remained functional throughout the vast Russian land empire. Mendeleev frequently commented on the inevitability of the metric system, but he rarely explained why he thought this to be the case. An examination of his metrological corpus, however, leaves us with a few ideas. It would seem that the central conveniences of the system were the primary reasons for its inevitability—decimal accounting, for example—but Mendeleev was aware that those conveniences could easily be incorporated into any system of measurement—a decimal breakdown of the *sazhen* or the *funt*, for example, would be easy to facilitate.[33] What made it inevitable, then, had nothing to do with the metric system *per se* or with its relationship to nature. What made it inevitable were man-made, arbitrary conventions, such as Russia's adherence to the international agreement, or the fact that other nations were converting and it was convenient for trade purposes. It is very important for Mendeleev's metric reform to understand that its appeal to him had nothing *natural* about it; it was precisely the *artificial* (in the sense of constructed) reasons for its adoption that he found most persuasive. It should be adopted because it was an appropriate and accepted convention; and its very status as an artificial convention determined the way it should be instituted.

Mendeleev's metric reform, then, was not about making Russia's measurement conventions adhere to a natural standard, but about making Russia's conventions adhere to a different set of conventions. Effective implementation of the metric reform would require labor to make the conventional nature of the standard appear natural. Hence the first stage of the reform: the standard exemplars of weights and measures needed to be recalibrated. Russia needed new prototypes not only for Russian units but for metric and British units as well (the only three major systems of units used in European spheres of influence). Before one could make the artificial natural, one needed to have standards of the artificial that could be treated as if they were natural. In 1892, before he officially became Director, Mendeleev informed his superior, Minister V. I. Kovalevskii, of 'the necessity of renewing them [the Russian prototypes], since all means which touch on the unification of weights and measures in the empire must, by their very essence, depend on the maintenance of prototypes. And thus the renewal of prototypes presents, judging by the examples of other countries, a very complicated affair. . .'[34] The 90% platinum-10% iridium prototypes were requisitioned from the London firm of Johnson, Matthey, and Co. in 1893. During the next five years Mendeleev produced a significant paper trail on how this stage was progressing, up to the final report upon reception of the prototypes in 1898.[35]

The reform's second stage was completed right after the first: the correlation of the Russian prototypes with exact metric equivalents. In the past, given the exact relation of the British weights to the Russian standards, it was simply more convenient to generate conversion tables between these two (and long overdue, since the last correlation between Russian units and any others was in 1835). It is not that Mendeleev was unconcerned with the ratios of conversion between the British and the Russian, but he wanted to relate both systems ultimately to the metric. The numbers of the conversion were not as neat as with the British system, and that was precisely the point. Because the metric system is just a convention, there was no reason to expect a neat relation, but the relation had to be established to make the transfer smoother.[36] The first two stages of the metric reform were completed by the promulgation of the 1899 law.

The third stage was also the most important, and its implementation was only begun under Mendeleev: the establishment of local verification stations distributed over the Empire. These bureaus were considered the most important element for the introduction of the metric reform, and they also dramatically illustrate the mechanisms of his plan.[37] The first mention of these establishments that I have been able to locate was in a series of memoranda in 1896. The idea was this: Russia is a vast empire, so if there were accurate metrological standards in Petersburg (located in one faraway corner), that would do nothing for standardizing the Empire, let alone getting the metric standards distributed to all localities. The answer was to divide the country into metrological zones (*oblasti*), each with its own verification bureau and team of 'verifiers.' These individuals were to inspect the trade and industrial measures in each region, enforce local standards, and serve as a way of correlating and standardizing the entire Empire.[38] These individuals were not just part of the metric reform—they were part of a larger reform meant to correlate *all* aspects of the entire Empire. The Chief Bureau took persons and standardized them to function as verifiers; then these were sent all over the Empire to follow the prototypes; their job was to correlate these measurements with all instruments and measures in use, and also with other local prototypes; and any developments were coordinated from the center.[39] But the Bureau did not dominate all the other bureaus in a sovereign power relation; rather, its power was constituted by the widespread distribution of the local bureaus—the more separate power nodes there were on a decentralized level, and the more they dispersed, the stronger the Chief Bureau became through the wider scope of its authority. The Chief Bureau worked beyond its localized site in St. Petersburg only to the extent that it invested each local bureau with part of its authority; these local bureaus returned the favor by making the authority of the Bureau more solid. No wonder one biographer of Mendeleev called these local bureaus 'control chambers', and Mendeleev himself wanted to expand the number of local verifiers even until the day 'when the entire Empire is *covered by a net* of local bureaus.'[40] The number of these bureaus was also meant to be rather large: given the 90 large districts (*gubernii*) and zones in Russia, there would need to be at least 100 fully stocked verification bureaus. And then an additional fifty smaller ones were to be partially equipped (with units of weight and length, but not the barometric, electrical, and the more specialized measures) in order to accommodate areas of heavy trade where demand was excessive. Only 22 of these local bureaus were built by 1917.[41]

The Bureaus were not just meant to standardize the measures in the Empire, however. They were also supposed to standardize people: both the verifiers and the verified. First the system of regulations was to be standardized by conferring all control over the local bureaus, which was originally under the joint jurisdiction of the Ministry of Finance and the Chief Bureau of Weights and Measures (itself under the Ministry of Trade), to the Chief Bureau exclusively.[42] The inspectors were all to be verified and standardized by training them in Petersburg and then distributing them to all the corners of the Empire—part of the process of dispersal of authority. They all had the same training protocols, the same notions of measurement, and, thanks to the renewal of prototypes, the 'same' standards in hand that they could carry to their separate zones (and, what was more, both men *and* women could serve as competent verifiers).[43] These local verifiers were deposited (along with their standards) in the local bureaus. But how does one standardize the practices from one bureau to the next? Mendeleev had two solutions for this: first, in order to foster coordination and to deal with people who were in areas too remote or whose equipment was too large to be brought to the bureau, two reserve (*zapasnyi*) verifiers per bureau were needed who could travel to where demand required; and then there were to be mobile bureaus, located on train wagons, which could travel around the country and standardize equipment wherever the tracks led.[44] The fabric of the net thus consisted of both stable 'control chambers' and mobile connecting nodes. Not only did Mendeleev create the supply of verifiers, however, he also created the demand. Under the 1835 and 1899 laws, verification of all local standards used by tradesmen and industries needed to be done once every three years. Mendeleev proposed moving it to an annual check—so the verifiers would always be circulating and standardizing—and then the impost fees paid for the standardization procedure would make the units self-financing. Furthermore, if there were annual checkups the bureaus could, through inspection certificates, collect data on economic activity and thus plug into the formulation of a more accurate industrial policy.[45]

Although the complete network of local establishments was not realized, it was initiated by the law of 1899, and was considered by Mendeleev a necessary component of the metric reform—as a precursor, in fact, to the fourth stage: the optional adoption of the metric system. (This stage was actually accomplished in 1899, so in this sense Mendeleev's reform was incomplete—or at least out of order.) Why, one might ask, if Mendeleev was so insistent on standardizing and controlling through circulation and networks, did he not push for mandatory adoption of the metric system? Mendeleev always conceived of the initial adoption of the metric system as optional, and for good reason. A mandatory adoption of the reform, as opposed to an optional approach, would be contrary to the efficacy he perceived in distributed power relations. Imposing the metric system, as had been done in France a hundred years earlier, would inspire popular hostility and invite failure. That is to say, if one *imposed* unity, it would be unstable, and thus undermine the very unity one desired. On the other hand, if verification establishments were distributed everywhere and if informal metric conventions were adopted, the people would be, so to speak, 'metricized,' and it would become second nature for them to adopt the system:

> I am of the opinion that to coerce popular habits, the popular will, the popular sense in this set of affairs is, so to speak, a sin. I am a great advocate of the metric system, but am still a greater advocate of the Russian people and its historically shaped condition. I would like, from my side, that our nation gradually, having the legal right to employ the metric system, express itself in favor of it. I know that the treasury departments could very easily order by a circular that a particular sort of system be employed. But the issue is how our nation will relate to it. It is easy to give an order. Thus it was done in France. . . and the people didn't accept it, even after thirty years!
>
> And thus, being an advocate of the metric system and understanding its advantages, I would like that it would be distributed by voluntary means in the Russian milieu, and I speak against the rapid and coercive introduction of it. I stand for the optional use of it, and chiefly for the introduction of verification establishments.[46]

The verification establishments offered a means to calibrate the population, which would then gradually, like a compass in a magnetic field, ally itself with the metric system. The important point is not to make the people's bodies metric, but their minds. As an optional program, Russian popular sentiment would not rebel against the change, and slowly their environment would change under their own will to make the Empire metric.[47]

Mendeleev was consciously employing a very specific theory of social relations throughout this metric reform. In recent work by historians of science on standardization and metrology, much emphasis has been given to what kind of society must be built in order for standardization to occur.[48] What kind of society was Mendeleev presupposing here?

Despite attempts by Soviet historians to argue otherwise, Mendeleev was far from a democrat; on the contrary, he remained a dedicated civil servant to the autocracy until his death. As Frances Stackenwalt has described elsewhere, Mendeleev had a highly historical conception of the evolution of the state. The state, just as the national economy, arose from the chaos of divided agents and centralized to provide greater order and civility in social relations. Mendeleev's state was not composed of individuals, Stackenwalt argues, the state *made* the very existence of individuals possible:

> [I]ndividual identity and the expression of self became possible only within the confines of the family clan, nation, and state. A single person, a Robinson Crusoe for example, who lived apart from his fellow man was a philosophical abstraction, an impossibility. . . . The state not only played a creative role in human development, but it provided mankind a moral order to insure his survival.[49]

The state, however, was not all-powerful, and there were legitimate limits to its authority. Those limits just did not happen to be individual interests: people may be economic units, but they were not political units. The state could not tell people how to behave, but it could establish a moral code that would let them realize the limits to their actions before the state had to intervene inappropriately.[50] It is my contention that metrology—the correlation of individuals carefully guided by a network so pervasive that its actions are unseen and unfelt—provided a mechanism for Mendeleev to correlate the behavior of individuals onto the correct path, that of a functioning civil society.

Evidence for this view can be found in Mendeleev's writings about unity and metrology. In his entire corpus of writings Mendeleev only wrote one article under a pseudonym (Popov, his wife's maiden name), entitled 'On Unity.' Responding to an article which argued that there was no such thing as a 'zero' in nature, Mendeleev argued that there was likewise no such thing as a unit. Like all other words and ideas, the 'unit' is just a convention: 'Units of measure, weight, time, any attractive force, in a word, any units which are usable in science are admittedly conventional. They do not exist, they are thought up by us ourselves, i.e., they are fictitious.' Only when the fact that a unit is conventional, that even our most cherished concepts of unity, be they scientific, individualistic, or religious, are realized to be conventional, will there be truth in our understanding of the world.[51] Attempts to find units in everything, to consider that there are atomistic individuals that act freely, only lead to the dangers of scientific skepticism. These forms of unity all fail because they are looking for unity in a *thing*, instead of in a *process*. This is where metrology enters the picture. There are some form of 'units' in nature—'individuals,' like Mendeleev's atoms—but they have no consequence unless they are integrated into a more general system—a 'unity' independent of 'units'—like the state, the economy, the metric system, or the periodic law.[52] Now we can explore how the chemical ether is explained through Mendeleev's metrological model of social organization, and how it relates to his pedagogy and the periodic table.

The Uses of Discipline

Mendeleev's metrology, then, is much more than a plan for the reform of weights and measures: it is an illustration of his general conception of the process of unification, a process that never *results* in a unity, but which constantly *produces* it through the correlation and standardization of diverse parts. Take, for example, the educational reform discussed at the outset: the key to maintaining a high standard of educational excellence is not uniform examinations—those are as unfruitful as a mandatory application of the metric system would be. The better alternative is to circulate inspectors who can coordinate the *process* of teaching, and thus correlate the various students in an orthopedic correction. The results are not as important as the means. It is his firm adherence to this view of an order that permits no violation that forces him to account for the ether in his periodic table. Anything less would have rejected a system he had spent his whole life in constructing—a system of social, political, economic, and scientific control.

These views are reproduced in his textbook, the one he was organizing when he came up with the periodic table. Perhaps surprisingly, Mendeleev does not reproduce his resolution of correlating terminology through the periodic table in the first volume of this two-volume textbook. The periodic law only appears at the beginning of the second volume, and it is used to organize the second half of the book into families, mostly of the metals. This makes sense historically, since he came up with the theory at the midpoint of his book,

but it does not explain why he never revised the structure.[53] Throughout all of its Russian editions he never bothered to change the structure of the book to introduce the law at the beginning, as a modern textbook would. Instead, he left the general structure as it was and just expanded his comments in the footnotes. So if the periodic table is not the organizing principle of the first volume, what is?

The answer, as should not be surprising, is metrology and standardization. The first volume of the textbook is about the scientific method and the chemical analysis of basic substances: water, nitrogen, table salt, and concludes with the halogens. This path, and the course of his footnotes, show us that his textbook is meant to do what most textbooks do—to standardize the students' views and knowledge of the subject matter. In a fashion similar to Mendeleev's future educational inspectors, the first volume of the textbook is designed to make sure that all the students using it (he insists that the rather sophisticated book is meant as an introduction) are all standardized with the same equipment, both physically and conceptually. This is a strategy common in textbooks, but Mendeleev's is unique in exactly how *explicitly* he formulates it. His introduction consistently stresses, recall the extended quotation above, the role of plans and hypotheses (along with measurement) in the formation of scientific laws. The way of calibration is the way of epistemological metrology, and the references in Mendeleev's book—mostly in the copious footnotes—are designed so that the students will know if their laboratory, thermometers, substances, and brains are calibrated accordingly.[54] Characteristically, in the second volume, once the static machinery of the periodic law is erected, the metrological apparatus slides into the background, and the new organizing principle seems to function with less conscious attention on the part of both Mendeleev and the experimenting student.[55]

The relationship of metrology to the order of the periodic law (and thus the ether) is captured in this transition between the two halves of the textbook—another aspect that differentiates Mendeleev's foundational textbook from, say, Lavoisier's. In the first half, Mendeleev shows how much effort must be expended in order to make a functioning chemical laboratory and student calibrated to all the others in the world. Likewise, the metric reform shows how much labor must be exerted by the itinerant inspectors and local bureaus in order to make sure that all weights and measures in the Empire are standardized. Once the first half of the textbook is complete, the periodic table may be introduced, and all the labor vanishes—or appears to. The work of calibration is still there, but the beautiful simplicity of the unifying *process* of the periodic law makes it recede into the background. The individual elements now seem to be calibrated by nature, although the work is still done by people.[56] Likewise, after the metric system becomes adopted optionally and used by the population, the work of calibration recedes into the invisible, just as we rarely think about standardization in our daily lives. Mendeleev's hostility to transmutation, so difficult to explain before, here intersects with this metrological disciplining. Mendeleev could not allow for transmutation between the elements because that would destroy the ability of any system, in his mind, to keep the units in line. The ether was necessary to preserve the order; it was an active disciplinary apparatus, whose functioning could be explained in the same way as the functioning of the Chief Bureau's metric reform. The ether allowed for the table to define a stable locality (as opposed to Prout's reckless homogenization), just as verification establishments in the metric system allowed for stable and correlated individual localities, instead of varying unities or false imposed unity (as in France's metric reform).[57]

Conclusion: Mendeleev's Failures

All in all, the consistency and breadth of Mendeleev's worldview is astonishing. His deliberate and conscious connections among disparate spheres of thought are reminiscent in the history of science of the characters of Isaac Newton and Antoine Lavoisier—whose successors Mendeleev so desperately wanted to be.[58] To some extent, he succeeded. He managed to create a worldview in chemistry that is still the fundamental pedagogical and classificatory system in use today. His economic policies also succeeded in boosting Russia's growth rate to one of the highest in Europe. And his metrological reform partially paved the way for the introduction of the metric system into Soviet Russia in 1918.

But perhaps some of the most astonishing successes of Mendeleev's worldview can be seen in how his notion of order functioned. A Foucauldian reading of his metrology as the underlying rationale behind his development of the periodic law may provide us with an alternative interpretation of the concept of 'discipline' in imperial Russia to the one offered elsewhere by Laura Engelstein.[59] According to Engelstein, in imperial Russia the exercise of discipline was never fully integrated with law, and thus when the Revolution was completed in 1917, discipline continued to be exerted outside the legal sphere. With no legal bounds to discipline, there was no civil society, no area where discipline could not reach. The allowance of a civil society does not end the disciplinary forces, but it establishes limits. I feel that, *pace* Engelstein, we see another possibility in Mendeleev's discipline. Discipline *is* linked to a pattern of law for Mendeleev, but it is natural law, not judicial law. His notion of correlation and calibration through the circulation of standards and inspectors provided limits for how disciplinary apparatuses could interfere, since if they interfered too much, they would destroy the very standardization that had been achieved. Had Mendeleev's worldview been actualized, a civil society—although one quite different from Engelstein's—would have emerged.

Unfortunately, this aspect of Mendeleev's reform failed. He never did manage to get those local bureaus established, and he never did see the popular use of the metric system. The ether was abolished, and the transmutation of the elements was widely accepted by his death. In fact, in 1906, less than a year before his death, he publicly renounced the chemical ether project. And Mendeleev's educational reform, including the banning of

examinations, was never adopted. As far as Mendeleev was concerned, Russia never made its Newtons. Mendeleev's system was a complete one, and the partial adoption of it was tantamount to no adoption at all. And thus after Mendeleev's death, there were no further attempts to resurrect his complete system for social reform. The Russian Empire died, as did Mendeleev, a system uncalibrated.

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Notes and References

1. M. V. Lomonosov, *Polnoe Sobranie Sochinenii* (Moscow: Akademiia Nauk SSSR, 1959), vol. 8, p. 206.
2. D. I. Mendeleev, *Sochineniia*, 25 vols. (Leningrad: Akademiia Nauk SSSR, 1952), vol. 23, pp. 97-98. All unattributed translations are mine. Transliterations are done according to a modification of the Library of Congress standard. All dates are given according to the old-style Julian calendar, which is twelve days behind the Western calendar in the nineteenth century, thirteen in the twentieth.
3. On Mendeleev's view that he was the next Newton, see D. Mendeléef [D. Mendeleev], *The Principles of Chemistry*, 3d. English edition, tr. G. Kamensky, 2 vols. (London: Longmans, Green and Co., 1905): vol. 2, pp. 472-3. This is a reproduction of his lecture at the Royal Institution of Great Britain on 31 May 1889 called "An attempt to apply to chemistry one of the principles of Newton's natural philosophy."
4. Mendeleev, *op. cit.* (2), vol. 23, p. 234. See pp. 74 and 228 on the banning of examinations; p. 83 on the need to construct a special 'Academy of Instructors' to train teachers.
5. *Ibid.*, p. 252.
6. The reading I am proposing here bears strong affinities to other recent works by historians of science. See, especially, the parallel accounts of Lavoisier by M. Norton Wise,"Mediations: Enlightenment Balancing Acts, or the Technologies of Rationalism," in Paul Horwich ed., *World Changes: Thomas Kuhn and the Nature of Science* (Cambridge, Massachusetts: MIT Press, 1993), 207–56; and of Hermann von Helmholtz by Robert M. Brain, 'Bürgerliche Intelligenze,' *Stud. Hist. Phil. Sci.*, 26 (1995), 617–35.
7. The role of the quantitative in Mendeleev's science has been disputed. Specifically, Henry Guerlac feels that chemistry remained a qualitative science in essence well into the twentieth century, despite the extensive quantitative developments in the nineteenth. Henry Guerlac, "Quantification in Chemistry," in Harry Woolf ed., *Quantification: A History of the Meaning of Measurement in the Natural and Social Sciences* (New York: Bobbs-Merrill, 1961), 64–84, on p. 66.
8. There has been a great deal of significant work recently by historians of science concerning the vital role metrology has played in the modern physical sciences. See, for example, Simon Schaffer,"Late Victorian metrology and its instrumentation: a manufactory of Ohms" in Robert Bud and Susan E. Cozzens eds., *Invisible Connections: Instruments, Institutions, and Science* (Bellingham, Washington: SPIE Optical Engineering Press, 1991), 23–56; and the essays collected in M. Norton Wise ed., *The Values of Precision* (Princeton: Princeton University Press, 1995).
9. An important forerunner to this is a piece that Mendeleev kept in his archives: Ch. Schinz,

Essai d'une Nouvelle Théorie Chimique (Lausanne: Imprimerie-Libraire de Marc Ducloux, 1841). Located at the Archive-Museum of D. I. Mendeleev, St. Petersburg State University, St. Petersburg, Russia [hereafter ADIM] 4/2. Mendeleev probably bought this copy while at Heidelberg University doing some postgraduate work under Bunsen. It is the only work listed under his 'Ether' catalog (done by Mendeleev himself) that was written before the 1880s. It bears a striking similarity to Mendeleev's own work on the ether, but I have not yet been able to establish evidence of direct intellectual ancestry. The fact that Mendeleev kept a copy of this small work for such a long time is suggestive, however.

10. A summary of these can be found in Howard Stein, "'Subtler forms of matter' in the period following Maxwell", in G. N. Cantor and M. J. S. Hodge eds., *Conceptions of ether: Studies in the history of ether theories, 1740–1900* (Cambridge: Cambridge University Press, 1981), 309-40. Mendeleev's chemical ether is not mentioned by Stein, nor are Stein's featured models mentioned by Mendeleev, although he did own many of the seminal works by Thomson and Maxwell.
11. On the role of the discovery of Mendeleev's predicted new elements in establishing his reputation, see Stephen G. Brush, "The Reception of Mendeleev's Periodic Law in America and Britain," *Isis*, **87** (1996), 595–628.
12. D. Mendeléef [D. Mendeleev], *An Attempt Towards a Chemical Conception of the Ether*, tr. G. Kamensky (London: Longmans, Green, and Co., 1904 [1902]), 2. This concern for measurement is also behind his rejection of the idea of ether as rarefied atmospheric gas: 'Hence the conception of the ether as a highly rarefied atmospheric gas cannot so far be subjected to experimental investigation and measurement, which alone can direct the mind in the right direction and lead to reliable results' (p. 3). The only secondary literature that deals with his chemical ether at length is Bernadette Bernsaude-Vincent, "L'éther, élément chimique: un essai malheureux de Mendéléev (1902)?" *The British Journal for the History of Science*, **15** (1982), 183–88.
13. On argon's unique role in reconceptualizing the table, see Erwin N. Hiebert, "Historical Remarks on the Discovery of Argon, the First Noble Gas" in Herbert H. Hyman ed., *Noble-Gas Compounds* (Chicago: University of Chicago Press, 1963), 3–20.
14. I am not addressing the particularities of coronium here since it does not play a large role in Mendeleev's treatise itself. Its chief function seems to be to round out the first period of the table so that the ether can be in both the 0-group and the 0-period.
15. Mendeléef, *op. cit.* (12), pp., 14–15 (emphasis his).
16. *Ibid.*, pp. 43–47.
17. On the perceived necessity of immutable elements for the periodic law, see Bernadette Bensaude-Vincent,"Mendeleev's periodic system of chemical elements," *The British Journal for the History of Science*, **19** (1986), 3–17.
18. Mendeléef, *op. cit.* (3), vol. 2, p. 33; Mendeléef, *op. cit.* (12), pp. 46–49 (where Mendeleev also expresses doubts about the existence of electrons). Mendeleev was frequently very public in his reaction to radium. For one example, see N. V. Gasanova,"Ob Odnom Interv'iu D. I. Mendeleeva," *Voprosy Istorii Estestvoznaniia i Tekhniki* (1983:4), 17–19.
19. While there are many such accounts, none is fully satisfactory. A first, and highly relevant such account associates it to Mendeleev's own unique formulation of atomism. For some statements, see Mendeléef, *op. cit.* (12), pp. 5, 17, among others. Throughout all his discussions of atomism, Mendeleev refers to the etymology of the word as the same as 'individual'. As we shall see, the political implications of this concept were not lost on him. Two other accounts try to ascribe to Mendeleev an adherence to either Comtean positivism or a variant of dialectical materialism, both without sufficient evidence. The positivist approach is offered in Bensaude-Vincent, *op. cit.* (12). Bensaude-Vincent's position is that Mendeleev's mistaken insistence on the measurable properties of the ether and his resolution of its chemical composition show just how fervently his positivism ran. These points are also made in Bensaude-Vincent, *op. cit.* (17), pp. 14, 17; Alexander Vucinich,"Mendeleev's Views on Science and Society," *Isis*, **58** (1967), 342–51, on p. 345; Frances Michael Stackenwalt, 'The Economic Thought and Work of Dmitrii Ivanovich Mendeleev,' (Ph.D. diss, University of Illinois, 1976), 25; and J. H. Kultgen, "Philosophic Conceptions in Mendeleev's *Principles of Chemistry,*" *Philosophy of Science*, **25** (1958), 177–183, on p. 179. A great many Soviet sources make the alternative claim for Mendeleev as dialectical materialist. Two that are distinguished in being particularly well-argued, thorough, and philosophically coherent are: P. P. Ionidi, *Mirovozzrenie D. I. Mendeleeva* (Moscow: Akademiia Nauk SSSR, 1959), pp. 3–4; and B. M. Kedrov, 'Nauchnyi metod D. I. Mendeleeva,' *Voprosy Filosofii* (1957:3), 19–34. For a Soviet

historian who finds the argument that Mendeleev is a proto-dialectical materialist unconvincing, see G. Zabrodskii, *Mirovozzrenie D. I. Mendeleeva: K Piatidesiatiletiiu so Dnia Smerti* (1907–1957) (Moscow: Gos. izd. politicheskoy literatury, 1957), pp. 8–9.

20. Mendeléef, *op. cit.* (12), pp. 32–3. On the rejection of the unity of matter in favor of the unity of laws, see Bensaude-Vincent, *op. cit.* (17), pp. 7–8. Mendeleev's opposition to Prout's primary matter and his call for the ultimate diversity of material elements is recounted in many places. See Vucinich, *op. cit.* (19), p. 342; B. M. Kedrov, *Mirovaia Nauka i Mendeleev: K istorii sotrudnichestva fizikov i khimikov Rossii (SSSR), velikobritanii i SShA* (Moscow: 'Nauka', 1983), pp. 79–87; and K. A. Timiriazev's account reproduced in A. A. Makarenia and I. N. Filimonova eds., *D. I. Mendeleev v vospominaniiakh sovremennikov* (Moscow: Atomizdat, 1969), p. 24.
21. Mendeléef, *op. cit.* (3), vol. 1, p. xiv, footnote 6. 'Realistic' in this quotation, as opposed to 'real', is a philosophical term which Mendeleev used to characterize his methodology.
22. See the accounts of V. I. Kovalevskii (Minister of Trade and Mendeleev's superior), A. A. Baikov and E. L. Rogovskii in Makarenia and Filimonova, *op. cit.* (20), pp. 128, 60 and 93, respectively. The single best secondary source on Mendeleev's metrology remains Iu. V. Tarbeev, 'D. I. Mendeleev—osnovopolozhnik otechestvennoy metrologii' in N. M. Zhavoronkov ed., *D. I. Mendeleev: 150 let so dnia rozhdeniia, 1834–1984* (Moscow: 'Nauka', 1986), 217–230. On Mendeleev's private scientific research into metrology, which I will not deal with here, see M. A. El'iashevich and T. S. Prot'ko, 'D. I. Mendeleev i Spektroskopiia,' *Voprosy Istorii Estestvoznaniia i Tekhniki* (1984:1), 34–43; and O. N. Pisarzhevsky, *Dmitry Ivanovich Mendeleyev: His Life and Work* (Moscow: Foreign Languages Publishing House, 1954), p. 23. See also, Nathan M. Brooks, "Mendeleev and Metrology," in this issue.
23. Quoted in Ionidi, *op. cit.* (19), p. 38.
24. Mendeléef, *op. cit.* (3), vol. 1, p. 1, fn. 1. Here Guerlac looks at this from the opposite side, arguing that the periodic law is an attempt to apply measurement to produce a qualitative result. See Guerlac, *op. cit.* (7), p. 84. I see it as rather the application of a qualitative assessment of metrology to produce systems of order such as the periodic law.
25. 'Disciplinarity' here refers to the concept developed by Michel Foucault throughout many of his works. It refers to a flexible, adaptive form of power that controls by constantly correlating and recalibrating various aspects of a complete network. See Michel Foucault, *Discipline and Punish: The Birth of the Prison*, tr. A. Sheridan (New York: Vintage, 1979).
26. This progression is dealt with at greater length by me in "Measure of All the Russias: Metrological Standardization and the Building of a Modern Empire," unpublished manuscript. See also E. I. Kamentseva and N. V. Ustiugov, *Russkaia Metrologiia* (Moscow: 'Vysshaia Shkola,' 1965), pp. 162 and passim.
27. Mendeleev, *op. cit.* (2), vol. 22, p. 26. Interestingly, almost all of the domestic advocates of the metric system in Russia were chemists like Mendeleev. In another context, it has been remarked that this is a more general phenomenon: 'To engineers such relations [of length to mass and specific gravity] are of small moment, and consequently among English-speaking engineers the metric system is making no progress, while, on the other hand, the chemists have eagerly adopted it.' Wm. Harkness, *On the Progress of Science as Exemplified in the Art of Weighing and Measuring* (Washington: Judd & Detweiler, 1888), pp. 64–65.
28. I will not deal with most of these here since they do not concern the metric reform, but they are of significant general interest. For example, on switching to the Gregorian calendar, see his memo of 9 (22) May 1900, Mendeleev, *op. cit.* (2), vol. 22, pp. 351–52. On the accurate measurement of the length of the day, see his letter to the powerful reactionary politician and Procurator of the Holy Synod Konstantin Petrovich Pobedonostsev, 21 October 1898, Mendeleev, *op. cit.* (2), vol. 25, pp. 588–89. On international standards for electromagnetic units, see the letter to V. I. Kovalevskii, 8 January 1895, Mendeleev, *op. cit.* (2), vol. 22, pp. 750–51. Much more information on these various reforms can be found in the journal of the Chief Bureau: *Vremennik Glavnoy Palaty Mer i Vesov*.
29. See Ken Alder's fine account, "A Revolution to Measure: The Political Economy of the Metric System in France," in Wise ed., *op. cit.* (7), 39–71. For other sources on the history of the foundation and reception of the metric system see Arthur E. Kennelly, *Vestiges of Pre-Metric Weights and Measures Persisting in Metric-System Europe 1926-1927* (New York: MacMillan, 1928); and Adrien Favre, *Les Origines du Système Métrique* (Paris: Les Presses Universitaires de France, 1931). On the turn-of-the-century status of the metric system in Western Europe and North America, see George Eastburn, *The Metric System* (New York: American Metrological Society, 1892).
30. On the role of international agreements in inducing Russian participation in the metric

system, and on the role of Russian scientists in establishing such international agreements to start with, see M. I. Radovskii, "K uchastiiu russkikh uchenykh v mezhdunarodnykh soglasheniiakh o edinstve mer i vesov," *Istoricheskii Arkhiv* (1958:2), 120–133; and Charles-Edouard Guillaume, *La Convention du Mètre et le Bureau International des Poids et Mesures* (Paris: Gauthier-Villars, 1902).

31. On imperial Russian metrological politics, see Kamentseva and Ustiugov, *op. cit.* (26), pp. 181–86; and William Hallock and Herbert T. Wade, *Outlines of the Evolution of Weights and Measures and the Metric System* (New York: MacMillan, 1906), pp. 71, 94. For the issues of World War I and the Soviet period see the pamphlet *Metricheskaia Reforma v SSSR* (Moscow: Tsentral'naia Metricheskaia Komissiia, 1928), p. 10.
32. An 1896 statement of this plan in a nutshell is available in Mendeleev, *op. cit.* (2), vol. 22, p. 557. A draft version of the final law, which includes the fullest expanded articulation of the project, is available in the manuscript 'Proekt, sostavlennyi Podkommisieiu v Glavnoy Palate Mer i Vesov 18-21 fevralia 1897 g.' [18–21 February 1897], ADIM 1038/6. The debates over the draft at the Ministry of Finance, which included Mendeleev's testimony, is another valuable tool to distill his personal vision of the project, which he defended against intense criticism: M. F., Department Torgovli i Manufaktur, *Zhurnaly zasedanii Kommisii po peresmotru deystvuiushchikh o merakh i vesakh uzakonenii* (St. Petersburg: Tip. V. Kirshbauma, 1897), ADIM 1034/6.
33. These inevitability statements are quite frequent: see, for example, Mendeleev, *op. cit.* (2), vol. 22, p. 26; and vol. 25, p. 560. On the use of decimal accounting in other systems, see vol. 22, p. 325.
34. Mendeleev, *op. cit.* (2), vol. 22, p. 29 (letter dated 21 December 1892).
35. The most significant documents with respect to this are the letter to V. I. Kovalevskii, 30 October 1893, Mendeleev, *op. cit.* (2), *ibid.*, pp. 727–30; 'The course of the work on the renewal of prototypes, or exemplary measures of length and weight,' 21 June 1895, *ibid.*, pp. 175–213; Letter to Minister of Finance S. Iu. Witte, [1895?], *ibid.*, p. 752; and the final report sent to Witte, 'The renewal of the prototypes or the fundamental exemplars of Russian measures, weight and length in 1893–1898,' 1898, *ibid.*, pp. 393–721.
36. Mendeleev, *ibid.*, pp. 44, 731, 746; and vol. 25, p. 552. The procedures of weighing required to make these determinations were minutely outlined by Mendeleev in vol. 22, pp. 215–23. The final table of conversions, which was also sent to the International Metric Commission in Paris, is reproduced in vol. 22, pp. 763–69.
37. Throughout, I have translated the word *palatka* as bureau (lower case), to show the symmetry between these smaller units and the Chief Bureau (*Palata*) in Petersburg, where Mendeleev worked.
38. For a few of the statements on the importance of these local bureaus for the metric reform, see Mendeleev, *op. cit.* (2), vol. 22, pp. 327, 328, 800, and 838. Its relation to the renewal of prototypes is described in a letter to V. M. Verkhovskii on 20 February 1898, in vol. 22, p. 770.
39. Mendeleev, *op. cit.* (2), vol. 25, p. 549.
40. Pisarzhevsky, *op. cit.* (22), p. 66. The Mendeleev quote is on Mendeleev, *op. cit.* (2), vol. 22, p. 794 (emphasis mine).
41. Mendeleev, *op. cit.* (2), vol. 22, pp. 796–97; Kamentseva and Ustiugov, *op. cit.* (26), p. 192. The final metrological document we have from Mendeleev, in fact, is a 1906 plea arguing for the full implementation of the metric reform by the establishment of the entire array of local bureaus. Mendeleev, *op. cit.* (2), vol. 25, p. 609. In fact, the battle was already lost by 1906: all 22 existing bureaus were completed by the end of 1904. The Ministry of Finances determined, in consultation with the Senate, that although the bureaus that existed displayed extraordinary profitability, these bureaus had already saturated all of the highly industrialized zones, and any further construction would go past the point of diminishing returns. This, in addition to the fact that the debacle of the Russo-Japanese War of 1904-5 had sapped the Imperial Treasury, doomed any further budget increases for the Chief Bureau, thus freezing the project. [D. I. Mendeleev],"Predstavlenie Ministerstva Finansov v Gosudarstvennyi Sovet o tom zhe [dalneyshem ustroistve mestnykh poverochnykh uchrezhdenii v imperii i o potrebnykh dlia sego kreditakh, a ravno o nekotorykh izmeneniiakh v deystvuiushchem zakone o merakh i vesakh i v shtate Glavnoy Palate mer i vesov]," 24 May 1907), ADIM 1052/5.
42. Mendeleev, *op. cit.* (2), vol. 22, pp. 792, 795, 847.
43. Mendeleev, *ibid.*, pp. 792, 845, 848. The gender aspect is particularly intriguing. Women were not allowed officially to work on the state rank system, but given that the Chief Bureau and its subsidiaries were not part of this system, an avenue was opened for the employment of women.

But Mendeleev did not recommend their hire from egalitarian impulses towards 'persons of the female gender' (as he invariably called them), but because he felt that accuracy and tedious precision were characteristics very appropriate for women. This did not require much intellectual input, just adherence to a protocol; even women could be standardized by the training program, *ibid.*, pp. 825–26. This is especially interesting given that, in Prussia, precision was gendered male and not neuter. This is because it was seen as something that required great patience and intellect—qualities women were not meant to have. See Kathryn M. Olesko, "The Meaning of Precision: The Exact Sensibility in Early Nineteenth-Century Germany," in Wise ed., *op. cit.* (7), p. 126.

44. On the need for reserve verifiers, see Mendeleev, *op. cit.* (2), vol. 22, pp. 793, 838 (where Mendeleev explains that they need to move around more than the police and tax-collectors and thus could perform some of their functions). On wagons see *ibid.*, p. 839
45. On the shortening of terms: Mendeleev, *ibid.*, p. 840. On self-sufficiency: *ibid.*, p. 837. On statistics-gathering: *ibid.*, pp. 842, 847–48. Although it sounded attractive, the shortening of terms was not adopted in the end.
46. Statement from the "Note from the protocol of the fourth [all-Russian trade-industrial] conference," August 1896, Mendeleev, *ibid.*, pp. 329–30.
47. A major mechanism for this change was for scientists and other lecturers to employ the metric system in their popular pronouncements, thus making people used to the system. This was his idea since 1869. See Mendeleev, *ibid.*, pp. 27, 746; and vol. 25, p. 553.
48. Especially valuable for my reading is Theodore M. Porter's approach to the standardization of social relations in "Objectivity as Standardization: The Rhetoric of Impersonality in Measurement, Statistics, and Cost-Benefit Analysis," *Annals of Scholarship* 9 (1992), 19–59; and Simon Schaffer's arguments about networks and empire in *op. cit.* (7). On unification of measures and the project of empire building, see M. Norton Wise, "Precision: Agent of Unity and Product of Agreement. Part I—Traveling," in Wise ed., *op. cit.* (7), p. 47; and the wonderful work by Witold Kula, *Measures and Men*, tr. R. Szreter (Princeton: Princeton University Press, 1986). An interesting Latourian reading of standardization as the circulation of particulars ('immutable mobiles') is given by Joseph O'Connell, "Metrology: The Creation of Universality by the Circulation of Particulars," *Soc. Stud. Sci.* **23** (1993), 129–173.
49. Stackenwalt, *op. cit.* (19), pp. 219–20.
50. Stackenwalt, *op. cit.* (19), pp. 221, 242.
51. Mendeleev, *op. cit.* (2), vol. 24, pp. 241–43, quotation on 241.
52. Metrology was consistently cited by Mendeleev as an important unifying principle for scientific, social, and economic relations. See Tarbeev, *op. cit.* (22), pp. 222, 228–29.
53. On Mendeleev's formulation of the periodic law during the construction of his textbook, see Bensaude-Vincent, *op. cit.* (17), p. 3; and Kedrov, *op. cit.* (19), p. 22.
54. References to experiments that will enable a student to calibrate their equipment abound in the textbook. See Mendeléef, *op. cit.* (3), vol. 1, pp. 49, 88, 128, 235, 242, 535, and 578.
55. Almost the only reference to metrology in the second volume appears in the chapter on platinum, and this is only to mention that standard weights and measures are built from a platinum alloy. Mendeléef, *op. cit.* (3), vol. 2, p. 396.
56. Lavoisier's text, on the other hand, constantly emphasizes how much care must be taken in measurement to ensure that the results are accurate. Characteristically, the bulk of the tables in Lavoisier's textbook consist of precise data concerning affinities, and not a schematic ordering abstracted from measurement. See Antoine-Laurent Lavoisier, *Elements of Chemistry in a New Systematic Order, Containing All the Modern Discoveries*, tr. Robert Kerr, introduction by Douglas McKie (New York: Dover, 1965).
57. It is also possible to extend this metrological analysis to Mendeleev's extensive economic work and his campaign against Spiritualism in Russia.
58. There are constant references in Mendeleev's work to his admiration of Newton and Lavoisier. For recent analyses of Lavoisier's work in a fashion similar to that presented here for Mendeleev, see Bernadette Bensaude-Vincent, "The Balance: Between Chemistry and Politics," *The Eighteenth Century*, **33** (1992): 217–237; and Jean-Pierre Poirier, *Lavoisier: Chemist, Biologist, Economist* (Philadelphia: University of Pennsylvania Press, 1997).
59. Laura Engelstein, "Combined Underdevelopment: Discipline and Law in Imperial and Soviet Russia," in Jan Goldstein, ed., *Foucault and the Writing of History* (Oxford: Blackwell, 1994), pp. 220–236.