A Modernization of "Peerless Homogeneity"

The Creation of Russian Smokeless Gunpowder

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In the final fifty years of its existence, the Russian Empire went through a series of modernizations that brought it closer than it had ever been to the industrialized economies of Western Europe. It is important to stress the plural of the somewhat hackneyed term "modernization," for the state-driven growth of the late-imperial period was not the result of a single decision or program by a cadre of ministers or any of the three Tsars who nominally led the effort; throughout this period, there were competing—often contradictory—visions of what it would mean for Russia to "modernize," and an even broader diversity of programs to achieve that variety of ends. The traditional emphasis on modernization as a singular, somewhat teleological process has obscured the richness of debate that took place locally, in the halls, laboratories, factories, and ministries of imperial St. Petersburg. There is an analogy here to the way historians of technology have attacked the fast-dying horse of "technological determinism." Like "mod-

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OCTOBER
2003
VOL. 44

ernization," a singular "determinism" is an ideology that attempts to impose simplicity on the past complexity of technological change. At this point, the notion that technology imposes autonomous and unidirectional change on society as a whole is widely rejected.[1] Nevertheless, arguments about the vital role of technology in forcing particular modernizations were quite common in the late nineteenth century. In this article, I explore one such effort to use technical primacy as the selling point for a military technology, and how the relevant consuming culture rejected an apparently superior technology precisely because it was marketed in those terms.[2]

One of the most crucial military technologies in this period was smokeless gunpowder, and at the center of the disappointing fate of Russian smokeless powder stands the St. Petersburg chemist D. I. Mendeleev (1834–1907), the formulator of the periodic system of chemical elements. From 1890 until 1893, between storming out of his post at St. Petersburg University and assuming the mantle of director of the Chief Bureau of Weights and Measures, Mendeleev was involved briefly but turbulently with the Russian navy in its quest for a viable smokeless powder.[3] This article traces the history of Mendeleev's research into smokeless gunpowder in the context of a rapidly modernizing Russia. A failure to treat Mendeleev's engagement with the military would be a grievous oversight for anyone wishing to understand the politics of science and technology in late-imperial Russia, a politics heavily centered on notions of "homogeneity" of all sorts. The story of Mendeleev's development of his "pyrocollodion powder," including its eventual rejection by the Russian military, not only highlights aspects of Mendeleev's character as a skilled manipulator of both society and technology; it is also an illuminating episode in the history of debates over the power of science and technology to influence history.

The case of Russian pyrocollodion is instructive for historians of Western military technology in several ways. In contrast to narratives of technology transfer, smokeless powder was not simply introduced from France or England and adapted to Russian circumstances—or, rather, that was only part of the story. While the army adapted French pyroxylin, Mendeleev and the navy strove to create a competing variant, so these two dueling technologies offer discriminating instruments with which to examine the internal structure of the development and procurement of military technology both within Russia and vis-à-vis Western Europe. Second, Mendeleev's pyrocollodion powder was created at the same time as and in explicit conjunction with an entire philosophical system about military modernization, enabling the historian to track the ideology embedded in the gunpowder.[4] Pyrocollodion, in addition, was a laboratory product that underscored the problems of linking science-in-the-lab to science-in-the-field (or factory), raising a set of concerns about scaling-up that have been usefully explored by historians of technology.[5] In this article, I begin with the context (international and domestic) in which pyrocollodion was conceived and created, and then follow the technology as it left the laboratory and Mendeleev attempted to sell it to wider and wider groups of military clients. The result throws into relief the usefulness of investigating the historical role of theories of technical change.[6]

1. Among the numerous valuable studies that make this claim, see, in particular: Wiebe E. Bijker, Thomas P. Hughes, and Trevor J. Pinch, eds., *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (Cambridge, Mass., 1987); Donald MacKenzie and Judy Wajcman, eds., *The Social Shaping of Technology*, 2d. ed. (Philadelphia, 1999); Merritt Roe Smith and Leo Marx, eds., *Does Technology Drive History? The Dilemma of Technological Determinism* (Cambridge, Mass., 1994); and Eric Schatzberg, *Wings of Wood, Wings of Metal: Culture and Technical Choice in American Airplane Materials, 1914–1945* (Princeton, N.J., 1999). For an interesting attempt to move beyond this deconstruction of the myth toward an alternative account of technology's reliability, see Edward W. Constant II, "Reliable Knowledge and Unreliable Stuff: On the Practical Role of Rational Beliefs," *Technology and Culture* 40 (1999): 324–57.

2. Abbreviations: ADIM—Arkhiv-Muzei D. I. Mendeleeva (D. I. Mendeleev Museum-Archive); *MS*—D. I. Mendeleev, *Sochineniia*, 25 vols. (Leningrad, 1934–1956); RGAVMF—Rossiiskii Gosudarstvennyi Arkhiv Voenno-Morskogo Flota (Russian State Archive of the Navy). All archives are in St. Petersburg, Russia, and are widely accessible to researchers. ADIM contains a fairly complete collection of documents authored by or addressed to D. I. Mendeleev in his various scientific and political activities, while reprints of many published documents are in *MS*. RGAVMF contains the complete documentation of navy material from Peter the Great to the Soviet period. The Russian Julian calendar lagged twelve days behind the Western Gregorian calendar in the nineteenth century, and thirteen in the twentieth. All dates are in the "Old Style" unless indicated by (N.S.). Transliterations according to the modified Library of Congress standard.

3. Unless specified as "black powder," "gunpowder" throughout this article refers to a substance's function—propelling projectiles out of a firearm. That is, smokeless powder, a chemical substance distinct from traditional black powder, will often be denoted as "gunpowder." This convention is suspended only in certain direct quotations, and I supply differentiation where ambiguous.

4. Similar accounts have been offered for military technology by Ken Alder, *Engineering the Revolution: Arms and Enlightenment in France, 1763–1815* (Princeton, 1997); Donald A. MacKenzie, *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance* (Cambridge, Mass., 1990) and *Knowing Machines: Essays on Technical Change* (Cambridge, Mass., 1996); and Michael H. Armacost, *The Politics of Weapons Innovation: The Thor-Jupiter Controversy* (New York, 1969).

5. Edward Jones-Imhotep, "Disciplining Technology: Electronic Reliability, Cold-War Military Culture and the Topside Ionogram," *History and Technology* 17 (2000): 125–75; David A. Hounshell and John Kenly Smith Jr., *Science and Corporate Strategy: Du Pont R&D, 1902–1980* (Cambridge, 1988); Walter Vincenti, "The Air-Propeller Tests of W. F. Durand and E. P. Lesley: A Case Study in Technological Methodology," *Technology and Culture* 20 (1979): 712–51.

6. Exemplary historicization of such invocations can be found in Alder; Gabrielle Hecht, *The Radiance of France: Nuclear Power and National Identity after World War II* (Cambridge, Mass., 1998); and Peter Galison and Barton Bernstein, "'In Any Light': Scientists and the Decision to Build the Superbomb, 1952–1954," *Historical Studies in the Physical and Biological Sciences* 19 (1989): 267–347.

Making Smoke History: Nitrocellulose Powders

OCTOBER
2003
VOL. 44

From the introduction of conventional ("black") gunpowder to the West in the fourteenth century until the end of the nineteenth century, the simple mixture of saltpeter, sulfur, and charcoal dominated warfare. Until the late eighteenth century, powder production was more a craft than a science, and experimental inquiry into its properties was contemporaneous with the troubles that ended France's ancien régime. Some of that research was state sponsored, as in France with Lavoisier's participation in the Régie for saltpeter production.[7] The nineteenth century saw two substantially different phases of scientific research into black powder. Early efforts, such as those of T. J. Rodman during the American Civil War, pursued a physical line of inquiry, attempting to control the efficacy of powder by altering the physical dimensions of the powder grains. In the second half of the century a chemical approach emerged, which focused on converting nitrocellulose explosives into workable gunpowders.[8] Smokeless gunpowder belonged to the latter category.

The desire for a smokeless gunpowder to replace black powder was universal in nineteenth-century Europe. The shortcomings of black powder became more pronounced as rifled, breech-loading, rapid-repeating small arms proliferated at midcentury. Black powder produced smoke, meaning that a portion of the charge—up to 57 percent—used to propel the bullet did not fully burn, wasting substantial fuel and reducing muzzle velocity for a given weight of charge. A smokeless powder, which oxidized its fuel entirely, would ideally convert all its fuel to projectile power in the form of evolved gases. The resulting increased muzzle velocities would mean greater accuracy and greater range, both advantages on the expanding battlefields of the nineteenth century. Black powder suffered from other disadvantages as well. Smoke particles fouled the gun barrel, diminishing the accuracy of the weapon by reducing the effect of the barrel's rifling; occasionally the powder residue ignited, destroying the weapon (and, often enough, the man firing it to boot). Solving the problem of fouling would

7. See Seymour H. Mauskopf, "From Rumford to Rodman: The Scientific Study of the Physical Characteristics of Gunpowder in the First Part of the Nineteenth Century," in *Gunpowder: The History of an International Technology*, ed. Brenda J. Buchanan (Bath, 1996), 277–93, and "Chemistry and Cannon: J.-L. Proust and Gunpowder Analysis," *Technology and Culture* 31 (1990): 398–426, on 404. On Lavoisier, see Mauskopf, "Gunpowder and the Chemical Revolution," *Osiris* 4 (1988): 93–118; Jean-Pierre Poirier, *Lavoisier: Chemist, Biologist, and Economist*, trans. Rebecca Balinski (Philadelphia, 1993), 89–94, 117–19; and Robert P. Multhauf, "The French Crash Program for Saltpeter Production, 1776–94," *Technology and Culture* 12 (1971): 163–81.

8. Mauskopf, "Chemistry and Cannon," 423, and "Bridging Chemistry and Physics in the Experimental Study of Gunpowder," in *Instruments and Experimentation in the History of Chemistry*, ed. Frederic L. Holmes and Trevor H. Levere (Cambridge, Mass., 2000), 335–65.

also mean that the gases evolved upon combustion could be used to reset breechloaders automatically, a key innovation in machine-firearms technology. Furthermore, eliminating smoke from the battlefield (especially from a naval battle) would enable commanding officers to acquire more accurate information about the course of the fighting and improve tactical decision making.[9] Eliminating smoke solved a host of technical, strategic, and tactical problems at once.

But it was easier said than done. As it turned out, finding a workable smokeless powder took the greater part of the nineteenth century, and even then it was successful only for a narrow, albeit important, range of weapon calibers.

In the early nineteenth century it was widely known that cellulose could become explosive when treated in certain ways. In 1832, Henri Braconnot of Nancy (and then Théophile-Jules Pelouze in 1838) found that nitric acid on starch formed a rapidly burning substance dubbed xylodine, or, more generally, nitrocellulose. In 1845–46, Christian Schönbein turned xylodine into guncotton (*Scheissbaumwolle*, *fulmicotton*, or pyroxyle) by treating it with sulfuric acid and drying it.[10] The new substance was immediately recognized as a potential substitute for black powder, but it took forty more years and many fatal failures to develop a stable, ballistically advantageous smokeless powder.

The first breakthrough came in France in 1884, with the work of Paul Vieille, a researcher at the French Laboratoire centrale. He had managed to reduce guncotton to a relatively stable mixture of homogeneous and inhomogeneous pyroxylin, which could be converted into a gunpowder when dissolved in a mixture of ether and alcohol.[11] Although the exact composi-

9. John B. Bernadou, *Smokeless Powder, Nitro-Cellulose, and Theory of the Cellulose Molecule* (New York, 1901), 164; Bruce W. Menning, *Bayonets before Bullets: The Imperial Russian Army, 1861–1914* (Bloomington, Ind., 1992), 104–6; Manuel Eissler, *A Handbook of Modern Explosives* (London, 1897), 181; Frederick Abel, "Smokeless Explosives," *Nature* 41 (1890): 328–30, 352–55; and Charles E. Munroe, "On the Development of Smokeless Powder," *Journal of the American Chemical Society* 18 (1896): 819–46, on 824 and 838–39.

10. Bernadou, 1–2; I. S. Dmitriev, "'Osobaia missiia' Mendeleeva: Fakty i argumenty," *Voprosy Istorii Estestvoznaniia i Tekhniki*, no. 3 (1996): 126–41, on 133; Eissler, v–vi. For a general overview of this history, see John Bernadou, "The Development of Smokeless Powder," a lecture delivered at the U.S. Naval War College on 20 July 1897, in Bernadou, app. 4.

11. On these French powders, see M. Barral, "Etudes des Poudres de Chasse Françaises et Recherche d'une Nouvelle Poudre de Chasse sans Fumée," *Mémorial des Poudres et Salpêtres* 5 (1892): 189–225; P. M. E. Vieille, "Researches upon the Nitraction of Cotton," in Bernadou, app. 1; M. Berthellot and P. M. E. Vieille, "Rapport sur l'Étude du Nitrate de Diazobenzol," *Mémorial des Poudres et Salpêtres* 1 (1882–1883): 99–108; P. M. E. Vieille, "Note sure l'Hydrocellulose et sur le Composé Nitré qui en Dérive," *Mémorial des Poudres et Salpêtres* 2 (1884–1889): 21–35; and Vieille, "Recherches sur la Nitrification du Coton," *Mémorial des Poudres et Salpêtres* 2 (1884–1889): 212–24. For a biogra-

tion of pyroxylin was never released, it was believed to be a compound of various nitrocelluloses and picric acid. It was soon replaced by the renowned Poudre B (just nitrocelluloses) and BN powder (nitrocelluloses mixed with barium nitrate and potassium nitrate for oxidation and sodium carbonate as a neutralizer), both hardened into celluloids.[12] Shortly thereafter two major competitors to the French pyroxylin powders emerged. In England, Frederick Abel had begun developing cordite, a double-base powder derived from nitrocellulose and nitroglycerin, as far back as 1865, and it quickly became the principal English propellant after its unveiling in 1891. In 1887, Alfred Nobel patented ballistite, the first smokeless powder based on nitroglycerin. It was between these three gunpowders, or derivatives of them, that military hierarchies caught up in the armaments race of the late nineteenth century had to decide.[13] Although higher-caliber weapons posed problems that remained unsolved, by 1890 most European states had either adapted their small-caliber weapons (rifles and pistols) to use smokeless powder or were on their way to doing so.

By no means slowest in this endeavor was the Russian army, administratively located in the Ministry of War, which with respect to both armaments and bureaucracy was distinct in important ways from the Ministry of the Navy. Experiments on smokeless powders began at the main Okhtenskii gunpowder factory in 1883. French engineers were brought over to help direct the engineering process toward French pyroxylin, but the venture went quite badly (including a few factory explosions). In 1889, Tsar Alexander III ordered work on "rifles of reduced caliber and cartridges with smokeless powder." Lieutenant General N. I. Chagin headed the experimental effort to generate .30-caliber rifles to complement the Russian powder, which was essentially a copy of French pyroxylin.[14] D. I. Mendeleev,

phy of Vieille, including a discussion of his formulation of the "shock wave," see Louis Médard, "L'oeuvre scientifique de Paul Vieille (1854–1934)," *Revue d'Histoire des Sciences* 48 (1995): 381–404.

12. Munroe, 830.

13. F. A. Abel, "Researches on Gun-Cotton," parts 1 and 2, *Philosophical Transactions of the Royal Society* 156 (1866): 269–308; 157 (1867): 181–253 ; Paul Everson and Wayne Cocroft, "The Royal Gunpowder Factory at Waltham Abbey: The Field of Archaeology of Gunpowder Manufacture," in Buchanan (n. 7 above), 377–94, on 392; and Ivan Ivanovich Vernidub, "One Hundred Years of Russian Smokeless (Nitrocellulose) Powder Industry," in Buchanan, 395–400, on 396. Attempts had been made to arm with smokeless powder even before these three types had emerged, although with dubious success. Leading the way was Austria-Hungary, which introduced guncotton in 1874 and then speedily abandoned it. The form they were using was a compactly wound thread for field guns, but it proved disastrous in the field and the Austrian factory in Hirtenburg blew up for undetermined reasons. Experiments had begun at Woolwich Arsenal in England even earlier (1867–1868) with compressed guncotton, but field usage led to so many problems that "much evidently remained to be accomplished before the requisite uniformity of action could have been secured." Eissler, 75. On Hirtenburg, see Munroe, 827.

14. Quotation from Menning, 104. See also Vernidub, 397; Dmitriev, 134; and A. Ia.

who had a long-standing interest in chemical explosives, was both at the time and subsequently severely critical of French involvement in the development of the army's powder.[15] The various disasters that marred the Russian army's involvement with the French were a large part of the reason why the navy wanted to turn to Russian scientists to engineer a gunpowder expressly designed to meet its specific needs.[16]

Those needs could not be met simply by copying a foreign smokeless gunpowder. One could not just heap more pyroxylin into a cannon to propel bigger shells, since that would also raise combustion temperatures and risk permanent damage to the gun, as well as increase the chances of spontaneous detonation. The forefront of nitrocellulose-powder research in the 1890s all over Europe was the formulation of a workable powder for heavy artillery. Nearly all war-bound naval vessels in Europe in the 1890s were ironclads, and it took substantial propellant force to penetrate their hulls. The switch to rapid-fire artillery also required clean gases to facilitate recoil-powered reloading. As a naval ministry report to the Naval Technical Committee put it on 28 May 1890: "In the Navy . . . smokeless gunpowder is absolutely necessary for rapid-fire shells, and thus the demands of the Navy cannot be satisfied by just the results of the trials carried out by the Ministry of War."[17]

Consequently, the navy initiated its own smokeless-gunpowder re-

Averbukh, "D. I. Mendeleev i Nauchno-tekhnicheskaia laboratoriia Morskogo vedomstva," *Trudy Instituta Istorii Estestvoznaniia i Tekhniki* 39 (1962): 222–47, on 231.

15. As he argued in an 1891 report to the navy, Okhtenskii's strong French design influence built in numerous flaws that could have been averted if a critical eye had been trained on the French. In his private 1890 laboratory notebook, Mendeleev wrote: "Everything is from the French, but stupidly done"; and "[The army] believes the French at their word, but they can swindle." Quotations from t. 2, l. 17a and t. 4, l. 13a of Mendeleev's gunpowder notebooks, reproduced in A. Ia. Averbukh, "Issledovaniia D. I. Mendeleeva v oblasti nitratsii: Otkrytie pirokollodiia," *Trudy Leningradskogo Tekhnologicheskogo Instituta* 30 (1954): 69–95, on 80. For the 1891 report's condemnation of French involvement, see *MS*, vol. 9, 48. On Mendeleev's interest in explosives, see Gordin, "No Smoking Gun: D. I. Mendeleev and Pyrocollodion Gunpowder," in *Troisièmes journées scientifiques Paul Vieille: Instrumentation, expérimentation et expertise des matériaux énergétiques (poudres, explosifs et pyrotechnie), du XVIe siècle à nos jours* (Paris, 2000), 73–96, on 76–77.

16. S. P. Vukolov, "D. I. Mendeleev i bezdymnyi porokh," *Zhurnal Prikladnoi Khimii* 7 (1934): 1535–38, on 1535.

17. RGAVMF f. 421, op. 2, d. 678, l. 89. See also Vice Admiral Pilkin and Manager Dmitriev to the General Administration of Shipbuilding and Equipment, 28 December 1890, RGAVMF f. 421, op. 2, d. 722, ll. 8–18; and Chikhachev to Minister of War P. S. Vannovskii, 19 February 1892, RGAVMF f. 421, op. 2, d. 768, l. 29. The problem with the Ministry of War's powder was that it was designed for small-caliber weapons like rifles, which inflicted 90 percent of land-combat fatalities; given that only 5 percent of fatalities came from cannon fire, it was understandable that the army had not focused on the unique problems posed by larger-caliber weapons. Mendeleev, Chel'tsov, and Fedotov to Chikhachev, 16 October 1890, *MS*, vol. 9, 37.

search program, largely independent of that administered by the army at Okhtenskii Armory.[18] I. M. Chel'tsov, the naval mining engineer who would become Mendeleev's chief collaborator on gunpowder and, later, the first director of the Naval Scientific-Technical Laboratory, had in fact been hired to work on pyroxylin for the navy as far back as 1878, although he had been unable to convert it into a workable naval gunpowder.[19] By the spring of 1890, Chel'tsov wanted to build a naval research laboratory for smokeless powders, and then, if possible, to collaborate with the army to work out a unified Russian variant.[20] The problem with Chel'tsov's proposals was Chel'tsov himself: he lacked the necessary diplomatic skills to get his programs off the drawing board. Chel'tsov recognized his limitations, and obtained authorization to invite Mendeleev to join the navy program. Since his return from postdoctoral research in Heidelberg in 1861, Mendeleev had been involved in a host of technical reform projects, mostly for the Ministry of Finance: alcohol-taxation reform, soil science, cheese manufactures, chemical industry, and—most notably—the 1891 "Mendeleev tariff," at the time the most protectionist in Europe. It was precisely because of the context of modernizations in the Russian state after the emancipation of the serfs in 1861 that technical experts such as Mendeleev gained increasing access to the halls of power. Mendeleev went further than anyone else both because of his position (the leading chemist at St. Petersburg University) and his own ambition to seek more influence for his projects.[21] Mendeleev had even consulted for the navy in the late 1870s about the possibility of acquiring military balloons. He accepted Chel'tsov's offer almost immediately, and they took the first opportunity, in the summer of 1890, to travel to England and France to obtain (with some difficulty) samples of foreign smokeless gunpowders, which they hoped to reverse engineer.[22]

OCTOBER
2003
VOL. 44

18. Overtures were made about establishing some sort of information clearinghouse for the two ministries, but I could detect no traces of anything actually being instituted. For an example of such an effort to establish "a defined order in the exchange of information and the communality (*obshchenie*) of both departments in questions of trials of smokeless gunpowder," see the report of the Technical Committee of the Artillery of the Ministry of the Navy to the Chief Artillery Administration, 18 January 1890, RGAVMF f. 421, op. 2, d. 678, l. 20ob.

19. P. M. Luk'ianov, *Istoriia khimicheskikh promyslov i khimicheskoi promyshlennosti Rossii do kontsa XIX veka*, v. 5 (Moscow, 1961), 354.

20. I. Chel'tsov, "K izucheniiu bezdymnogo porokha," 24 April 1890, RGAVMF f. 421, op. 2, d. 678, ll. 83–84. See also L. Fedotov, "Ob ustroistve laboratorii dlia ispytaniia bezdymnykh porokhov," 30 April 1890, RGAVMF f. 421, op. 2, d. 678, ll. 85–87.

21. For more on Mendeleev's reformist activities in the Russian bureaucracy, see Michael D. Gordin, "The Ordered Society and Its Enemies: D. I. Mendeleev and the Russian Empire, 1861–1905" (Ph.D. diss., Harvard University, 2001), especially chap. 6.

22. Gordin, "No Smoking Gun" (n. 15 above), 73–74.

Shooting Daggers: Russian Rearmament after Crimea

When Mendeleev came upon the Russian military in 1890, he encountered an institution entirely transformed, both technically and sociologically, and quite uncertain about whether technological modernization boded well or ill for the stability of Russian forces. Amid the traumas of military modernization Mendeleev was not just proposing a minor technological improvement: he was proposing modernization to an audience that was not at all sure whether they could trust yet another guru of progress.

The Great Reforms of Alexander II, precipitated by the Russian rout in the Crimean War (1854–56), left few traditional imperial institutions untouched. While most historical attention has been trained on the first of these reforms, the 1861 emancipation of the serfs, a series of concomitant military reforms, especially the universal military draft of 1874, may have had even more far-reaching effects. Military transformation had begun long before the draft. Newly appointed Minister of War Dmitrii Miliutin decentralized military administration on 6 August 1864 and reformed military education in order to create a new generation of military bureaucrats to administer a modern fighting force.[23] This administrative transformation was followed by a social leveling in the military that led to the infiltration of lower social groups into the traditionally noble preserve of the officer corps, prompting worries about loyalty and competence.[24]

23. On the reforms of the army, see Peter von Wahlde, "Russian Military Reform: 1862–1874," *Military Review* 39 (1960): 60–69; Dietrich Beyrau, *Militär und Gesellschaft im vorrevolutionären Russland* (Köln, 1984); Forrestt A. Miller, *Dmitrii Miliutin and the Reform Era in Russia* (Nashville, Tenn., 1968). Although Miliutin is often given credit for the reforms of the military, one can see the genesis of many of the subsequent policies under Sukhozanet, his predecessor. See E. Willis Brooks, "Reform in the Russian Army, 1856–1861," *Slavic Review* 43 (1984): 63–82. For a criticism of the decentralization policies as a panacea, see John L. H. Keep, *Soldiers of the Tsar: Army and Society in Russia, 1462–1874* (Oxford, 1985), 355. Perhaps the only military branches to escape overhauling were the artillery and engineering corps, both of which were already well-organized in terms of expertise and merit under Nicholas I, and so were not distracted by the martinet-like orders of Nicholaevan officers who valued presentation above performance. See Miller, 62; Peter Kenez, "A Profile of the Prerevolutionary Officer Corps," *California Slavic Studies* 7 (1973): 121–58, on 136; John Shelton Curtiss, *The Russian Army under Nicholas I, 1825–1855* (Durham, N.C., 1965), 148–51; and John Bushnell, "The Tsarist Officer Corps, 1881–1914: Customs, Duties, Inefficiency," *American Historical Review* 86 (1981): 753–80.

24. There is debate about the degree of social leveling. Some historians have argued that it was in fact quite substantial: see Kenez; Roberta Thompson Manning, *The Crisis of the Old Order in Russia: Gentry and Government* (Princeton, N.J., 1982), 31; John S. Bushnell, *Mutiny amid Repression: Russian Soldiers in the Revolution of 1905–1906* (Bloomington, Ind., 1985), chap. 1; and Walter M. Pintner, "The Burden of Defense in Imperial Russia, 1725–1914," *Russian Review* 43 (1984): 231–59, on 257. This view is contested by Seymour Becker, who argues that when measured accurately, and accounting for expansion of forces, the decline of the nobility in the officer corps is easily exag-

The third transformation was technical, often dubbed the Russian "firearms revolution." The Crimean War convinced many that the .70-caliber smoothbore, muzzle-loading musket that had been the staple of Russian small arms since the early eighteenth century had to be replaced. In 1857 a .60-caliber rifled muzzle-loader made in Germany and Belgium was introduced, and 260,106 of these *vintovki* were issued by 1862. The 1866 Austro-Prussian war demonstrated to European observers that breech-loading substantially increased firing rates. Russian officials now had to decide whether to acquire new weapons or modify the *vintovki*; they opted for both, with rather poor results. There were substantial problems in sealing the breeches of Russian guns, which decreased accuracy and muzzle velocity, and the benefits of rifling for the artillery were ambiguous given tradeoffs in training and reloading.[25] When war broke out with Turkey in 1877, Russia's substantial military reforms were put to the test—and found wanting. Russia's victory was narrower than it should have been against a second-tier power, and many construed the reforms as failures.[26]

OCTOBER
2003
VOL. 44

The navy was transformed as much as, if not more than, the army. Grand Duke Konstantin Nikolaevich, Alexander II's brother, had been appointed minister of the navy at the start of the Crimean War, and he and his advisors fashioned an extensive reform program.[27] The Black Sea clauses imposed on Russia by Britain after the war forbade the establishment of a Black Sea fleet, so a subsequent modernization and overhaul of the Baltic Sea fleet was undertaken, culminating in an 1880 plan to rebuild the fleet in twenty years.[28] The navy also had difficulties rearming. While the army managed to modernize its guns, albeit haltingly, naval artillery was among the slowest branches of the armed forces to modernize, despite the international accolades brought by Admiral S. O. Makarov's performance in winning the world's first torpedo battle during the Russo-Turkish War. It lagged most seriously in large-caliber howitzers, precisely the guns required for the new ironclad vessels.[29] Since clean-burning powder was needed to sustain rapid-fire shelling without fouling, the lack of nitrocellulose powder for large-caliber weapons handicapped the navy's entire modernization program. Thus, when Mendeleev first sat down in his laboratory to perform nitration experiments, many competing interests in the Russian military were prepared to attribute decisive significance to his results.

gerated. See his *Nobility and Privilege in Late Imperial Russia* (DeKalb, Ill., 1985), 109. On ideological stability amid social transformation, see the excellent account in A. V. Fedorov, *Russkaia Armiia v 50–70 gg. XIX v.* (Leningrad, 1959), chap. 4. For an interesting analysis of radicalism in the military during the period of Mendeleev's involvement, see Norman M. Naimark, *Terrorists and Social Democrats: The Russian Revolutionary Movement under Alexander III* (Cambridge, Mass., 1983), chap. 5.

25. Joseph Bradley, *Guns for the Tsar: American Technology and the Small Arms Industry in Nineteenth-Century Russia* (DeKalb, Ill., 1990), 13–14, 21, and passim; Menning (n. 9 above), 30–31. Russia also had extensive arms dealings with Krupp. See Maurice Pearton, *The Knowledgeable State: Diplomacy, War and Technology since 1830* (London, 1982), 83.

26. John S. Bushnell, "Miliutin and the Balkan War: Military Reform vs. Military Performance," in *Russia's Great Reforms, 1855–1881*, ed. Ben Eklof, John Bushnell, and Larissa Zakharova (Bloomington, Ind., 1994), 139–58; Menning, 85; and Carl Van Dyke, *Russian Imperial Military Doctrine and Education, 1832–1914* (New York, 1990), 84.

27. Judicial and administrative reform of the navy included ending arbitrary sentencing (1867), abolishing corporal punishment (1863), and substantially unifying naval administration. Aurele J. Violette, "The Grand Duke Konstantin Nikolayevich and the Reform of Naval Administration, 1855–1870," *Slavonic and East European Review* 52 (1974): 584–601; Violette, "Judicial Reforms in the Russian Navy during the 'Era of Great Reforms': The Reform Act of 1867 and the Abolition of Corporal Punishment," *Slavonic and East European Review* 56 (1978): 586–603.

28. Jacob W. Kipp, "Consequences of Defeat: Modernizing the Russian Navy, 1856–

A Room of One's Own: The Scientific-Technical Laboratory

Mendeleev began his project to create a new gunpowder and a new military by creating his laboratory. The idea of a state-run laboratory for explosive substances was not new. Lavoisier had directed one in ancien régime France, and France and England had revealed to Mendeleev the benefits of active research on nitrocellulose substances. Mendeleev was convinced that smokeless gunpowder in itself demanded such research, and if Russia had so far survived without a stable research environment for black powder, it could no longer do so. Proper organization was central, as he wrote in his personal gunpowder research notebook in 1890:

> The currently established Chief Organizational and Executive committees, which are carrying out the entire rearmament matter, and consequently also the matter of gunpowder production, along with the inspector of gunpowder factories, cannot possibly address in detail all of the conditions which can serve to lower the cost and

1863," *Jahrbücher für Geschichte Osteuropas* 20 (1972): 210–25. On the 1882 buildup, see Anthony J. Watts, *The Imperial Russian Navy* (London, 1990), 14–16; and David Woodward, *The Russians at Sea: A History of the Russian Navy* (New York, 1965), 117. The year 1859 was in fact a historic watershed for navies in general: it was the last year in which navies measured their strength by the number of wooden line-of-battle ships. After this, ironclads became the staple of the modern fleet. Woodward, 107.

29. On Makarov and the torpedo battle of 25 May 1877, see Fred T. Jane, *The Imperial Russian Navy: Its Past, Present, and Future*, rev. ed. (London, 1904), 200. On naval arms, see Menning, 273. The Russian navy was idiosyncratic in its preference for light artillery. Russians opted for 3-inch shells instead of the European standard of 4.7-inch, and 10-inch where other European powers used 12-inch. Jane, 154. Naval rearmament was occasionally buffeted by disaster. In 1894 the new warship *Sissoi Velikii* was sent to the Mediterranean, where its gun turret blew off during a training exercise. Apparently the turret was armed with two different guns, and the experimental one, whose breechblock was unlocked, looked much like the standard gun when locked. The experimental gun was fired by accident, the breechblock blew off, and several sailors died. In general, however, naval Obukhov guns did not burst. Jane, 286, 520.

OCTOBER
2003
VOL. 44

> improve the preservation of the qualities of a gunpowder so new in industrial terms as pyroxylin, because this gunpowder comprises a new product in chemical terms, deeply differing from regular gunpowder, and demanding a most fundamental familiarity with chemical reactions and products. . . . In view of these considerations I consider the establishment of a new institution entirely unavoidable, an institution which is free of all traces of direct authority, and designated for the chemical-technical supervision of the production of smokeless gunpowder and for the recognition of competent judgments of the purely chemical-technical properties relating to the new [powder]. . . .[30]

The standard argument for military reform was to point out that Western European powers were conducting such research, and Mendeleev emphasized that almost all major European states were gearing up for factory production of smokeless powders. As Mendeleev and his colleagues wrote to the minister of the navy, Chikhachev, on 16 October 1890:

> Such laboratory researches can very significantly shorten the term for the experimental estimation of the new sorts of powder by continuous artillery tests. Simply using the prepared types of powder cannot serve for the supply of the Russian fleet of the desired, and possibly completely smokeless, powder, because none of the known types of smokeless powder has behind it continuous, experimental artillery estimation, and the smallest change in the composition or means of preparation of smokeless powder can make it either barely useful (for example, tending to create pressures that destroy the insides [of the guns]) for a specific shell or [make it] significantly change in the intervening time and with fluctuations in temperature, or, finally with inhomogeneities in various shells, that strongly lower the efficacy of any powder.[31]

As he reported to the army on 27 November 1890, staffing the military with the right chemical experts would solve many gunpowder problems:

> I cannot do everything by myself and, I admit, I am afraid to be morally responsible in a matter of such great importance, although I am prepared to devote my remaining powers to the matter of Russian military might, because I consider such a matter a satisfactory conclusion of a life dedicated to science. Thus, I considered it my duty to bring into the open: 1. The necessity of inviting to the matter of smokeless gunpowder several Russian scientists who can grasp the

30. Mendeleev's gunpowder notebooks, t.4, ll. 4–5, reproduced in Averbukh, "Issledovaniia D. I. Mendeleeva v oblasti nitratsii" (n. 15 above), 78.

31. *MS*, vol. 9, 38.

> current tasks in their breadth. 2. The necessity to form from them a special committee on explosive substances. 3. The necessity to equip this committee not with sole authority, but with trust to its knowledge and the right of scientific control in all issues which relate to smokeless gunpowder, and 4. The necessity to give to the committee all the means required for the new laboratory study of explosive substances and for the systematic scientific control of the study of questions related to this, in order to form the necessary kernel of autonomous experts of this branch of science. . . .[32]

Approval for the establishment of the Naval Scientific-Technical Laboratory was forthcoming, and Mendeleev—although officially only a consultant—immediately began to organize it and integrate it into the military hierarchy.[33] A suitable site was quickly found on the island of Novaia Gollandiia (New Holland), in the center of the Admiralty Canal in St. Petersburg.[34] (A naval installation still stands on the island today.) One of the laboratory's main intended functions was to mimic large-scale production.[35] This ethic of industrial production even extended to proprietary rights for Mendeleev after he left the laboratory. In 1898, Chel'tsov wished to employ a specific nitration process that Mendeleev had pioneered, but he insisted on recognizing Mendeleev's rights: "But Professor Mendeleev, having discovered this means of nitration, in his time reserved the right for all further study of it exclusively with himself, and by general custom, strictly observed

32. ADIM II-Zh-51-1-1, quoted in Averbukh, "D. I. Mendeleev i Nauchno-tekhnicheskaia laboratoriia Morskogo vedomstva" (n. 14 above), 231–32, ellipses added. Mendeleev listed as potential members of this committee: Leon Nikolaevich Shishkov, former professor of the artillery academy; Aleksei Romanovich Shuliachenko, chemist at the engineering academy; Chel'tsov; and Grigorii Aleksandrovich Zabudskii.

33. Mendeleev's first letter to Chikhachev, on 2 May 1890, in fact mentions the need for a fully equipped laboratory (ADIM Alb. 2/474). The "consultant" position was meant for someone who was "especially well-known for his works in the field of the physico-chemical sciences," and it was essentially tailor-made for Mendeleev after he had already been selected. RGAVMF f. 421, op. 2, d. 722, ll. 8–18. As a consultant, Mendeleev was also freer to quit at will. Mendeleev mentioned in his 1898 commentary on his curriculum vitae that the charter of the laboratory "was put together by Chikhachev, generally following my suggestions"; "Spisok sochinenii," reproduced in *Arkhiv D. I. Mendeleeva: Avtobiograficheskie materialy, sbornik dokumentov* (Leningrad, 1951), 90. On personnel issues in the laboratory, see P. M. Luk'ianov, "O neizvestnykh pis'makh D. I. Mendeleeva i arkhivnykh dokumentakh, kasaiushchikhsia ego rabot po pirokollodiinomu porokhu," *Nauchnoe Nasledstvo* 2 (1951): 257–68, on 257–58.

34. Report of Chief Engineer-Builder of St. Petersburg Port, 12 June 1890, RGAVMF f. 421, op. 2, d. 678, ll. 108–10. For the specifications of the laboratory, see Vice Admiral Kaznakov, "Izmenennyi proekt polozheniia o laboratorii Morskogo Ministerstva dlia issledovaniia porokhov i vzryvchatykh veshchestv" (fall 1890), RGAVMF f. 421, op. 2, d. 678, ll. 179–82.

35. Mendeleev and Chel'tsov to the Chief Inspector of Naval Artillery, 5 February 1892, RGAVMF f. 421, op. 2, d. 768, ll. 6–7.

among chemists, without his permission no one else can turn to its study."[36] Amazingly, the navy agreed.

Mendeleev did discover a smokeless powder while borrowing space from St. Petersburg University's chemical laboratories during the construction of the New Holland site. The samples of France's and England's nitrocellulose powders that Mendeleev had obtained soon proved inadequate for the original project of reverse engineering. All powders then on the market, it turned out, had severe flaws that made them unusable for naval artillery. Pyroxylin was inhomogeneous in composition, which led to irregular burning and thus irregular pressures, often damaging the interior of the gun. Vieille's pyroxylin was also only stable for temperatures between 50 and 110 degrees Centigrade, but naval guns frequently generated higher temperatures, disintegrating the gunpowder.[37] Furthermore, pyroxylin could detonate spontaneously; in the early 1890s, two French ships, the *Iéna* and the *Liberté*, were rocked by explosions set off by spontaneous detonation of powder on board. Abel's cordite and Nobel's ballistite, both having nitroglycerin components, tended to burn too hot, causing damage to the inside of the gun barrel.[38] Mendeleev would have to start from scratch.

His approach was one that had produced results over his entire career: he would abandon empirical reasoning and start with theory, deriving the best possible solution, and then try to actualize that ideal formula—the same approach that had spawned the periodic law. Mendeleev needed a substance that was entirely soluble (so it could form a good powder) and that evolved the greatest possible volume of gases for a given weight. He would worry later about physical properties like temperature invariance, stability over time, and smooth burning. Since the substance would be a combination of hydrogen, oxygen, nitrogen, and carbon—light elements that were components of all explosives—Mendeleev deduced that the ideal formula should take the form of $C_nH_{2m}N_qO_{n+m}$. Upon total burning, this would evolve the maximum amount of gas for the least weight, and Mendeleev considered the limiting case, the most perfect smokeless powder possible—$C_{30}H_{38}(NO_2)_{12}O_{25}$, dubbed "pyrocollodion." It would burn into $30CO + 19H_2O + 6N_2$, and could be easily formed by a simple polymerization of five molecules of cellulose ($C_6H_{10}O_5$) with nitric acid. Once Mendeleev had deduced the theoretical structure of the compound, he was indefatigable, working each day from nine in the morning until six or seven

36. Chel'tsov to Chief Inspector of Naval Artillery, 14 September 1898, RGAVMF f. 421, op. 2, d. 1089, l. 58ob.

37. *MS*, vol. 9, 31.

38. Vukolov (n. 16 above), 1536; *MS*, vol. 9, 36. Ballistite did possess just the right amount of oxygen for total burning, however, which meant that it could burn independently of specific external conditions (p. 34). Mendeleev would try to replicate this property.

at night attempting to synthesize the substance.[39] When he finally tried to dissolve it in a mixture of alcohol and ether, he exclaimed with glee to his assistant, S. P. Vukolov: "Look, look, it dissolves like sugar!"[40] When it turned out this substance did not detonate spontaneously like pyroxylin, he had even more cause to celebrate. With a fixed nitrogen content, Mendeleev could claim to have developed a smokeless powder with greater homogeneity than any other. Making homogeneity a compelling selling point for others was another matter.

The Well-Ordered Chemical State: Homogeneity

Post-emancipation Russia was both a state undergoing transformation and a culture striving for unity. Mendeleev made smokeless gunpowder a means of addressing this desire by his use of the category "homogeneity" (*odnorodnost'* or *odnoobrazie*). Pyrocollodion was for Mendeleev a perfect substance because it was homogeneous, and because it was homogeneous it could serve as an exemplar and a metaphor for how to reform and unify the Russian military—a necessary project because the army and navy served as bulwarks for the autocratic state, which was coming unravelled. Mendeleev employed an explicitly metaphorical rhetoric of homogeneity to sell pyrocollodion to the navy and then to the armed forces generally.[41] In each case, the language used and the explanations given are Mendeleev's own, even in the increasingly "social" realms that came to be included in his metaphor as broader and broader swaths of contexts were embedded in Mendeleev's terms.

Mendeleev insisted that pyrocollodion, unlike pyroxylin or cordite, was a single chemical compound, not a mixture of several compounds, and thus was chemically homogeneous. He was frequently explicit about this elementary (no pun intended) form of homogeneity: "As to its chemical composition, pyrocollodion may be designated *homogeneous*, and herein consists one of its most important qualities. All previous and present forms of powder did not have and do not have this property to the degree here implied. From their very method of preparation, black and brown powders

39. P. P. Rybtsov, "Ocherk deiatel'nosti Dm. Iv. Mendeleeva v oblasti izucheniia vzryvchatykh veshchestv," in *Trudy pervago mendeleevskogo s"ezda po obshchei i prikladnoi khimii, sostoiavshagosia v S.-Peterburge s 20-go po 30-go dekabria 1907 g.*, ed. V. E. Tishchenko (St. Petersburg, 1909), 152–61, on 157.

40. Quoted in Vukolov, 1537. Mendeleev detailed the production process of pyrocollodion from cellulose on the first page of his *Morskoi Sbornik* article (*MS*, vol. 9, 257, 264), which only articulated the process and the theoretical reasoning, keeping the formula still secret. ADIM Bib. I-1032-12, l. 1, quoted in Averbukh, "D. I. Mendeleev i Nauchno-tekhnicheskaia laboratoriia Morskogo vedomstva" (n. 14 above), 236.

41. I use "rhetoric" here in its original sense of language employed for the sake of persuasion.

are coarse mechanical mixtures, for which any consideration of homogeneity is out of the question."[42]

Chemical homogeneity was occasionally cited by Mendeleev as important for practical reasons—for example, it was possible to test the purity of a particular batch of pyrocollodion simply by measuring its weight and volume.[43] Furthermore, pyrocollodion was also homogeneous in time, in that it was not susceptible to spontaneous detonations or decay due to humidity or aging.[44] To be fair, Mendeleev was aware that he could not claim absolute homogeneity for his powder, and in a lone footnote he hazarded a qualification: "About complete chemical homogeneity in the purely scientific sense one is not and should not be speaking, as even in cellulose itself there is no certainty. One speaks of relative or technical homogeneity, compared with other types of smokeless (and, of course, smoky) gunpowder."[45]

This ideal of homogeneity was not drawn out of thin air. The issue had long concerned gunpowder specialists, as is indicated by an 1868 article in Britain's *Quarterly Review*, referring to black powder:

> As powder varies in density, so it varies in the size and shape of its grains. The system of cracking up the press-cake into grains in the granulating machine, produces fragments of all shapes and size; the latter are of course restricted to a certain extent by the siftings the powder undergoes, but no two powder grains are alike. It follows therefore from what has been said, that no two charges of gunpowder made in the present way will produce exactly the same *force brisante* in the guns from which they are fired. . . . The problem of the day in gunpowder has therefore been to manufacture a perfect powder, in which each grain shall be the same in all respects as its fellow; the disruptive effects of which shall be, to a certain extent, under control by modifications of manufacture; and the results of which shall be uniform.[46]

Closer to home, as Vice Admiral Popov made clear in a letter to the Russian Society for the Production and Sale of Gunpowder in 1892, the issue of black powder's homogeneity (in terms of its stability) was a dominant concern: "Can we expect constancy in the gunpowder during its storage, what conditions must be observed during storage and what kind of differences can one expect in the course of the year in ballistic properties, if all the conditions during storage are fulfilled[?]"[47] Mendeleev translated these

42. Mendeleev, "Pyrocollodion Smokeless Powder," app. 2 in Bernadou (n. 9 above), 97–98.

43. *MS*, vol. 9, 185 n. 3.

44. Mendeleev to Chikhachev, June 1895, *MS*, vol. 9, 196.

45. *MS*, vol. 9, 254 n. 1.

46. "Gunpowder," *Quarterly Review* 125 (1868): 106–33, on 131–32. Ellipses added.

47. Popov to the Russian Society for the Production and Sale of Gunpowder, 29 January 1892, RGAVMF f. 427, op. 2, d. 305, l. 27.

concerns into the language of homogeneity and transferred them to smokeless powders.

Mendeleev continued to develop this ideal, extrapolating further and further from the strict chemical sense. He stressed pyrocollodion's caliber homogeneity—that is, its ability to be used in any caliber weapon. Pyrocollodion burned uniformly, and not in fits and starts—a consequence of its chemical homogeneity. Because it burned in a laminar fashion (layer by layer), the thickness of a pyrocollodion charge was all that needed to be adjusted to move from pistol sidearms to naval howitzers.[48]

A third rhetorical sense involved ballistic homogeneity. Mendeleev noted that when field tests of pyrocollodion were begun in April 1893, the muzzle velocities produced were almost entirely constant at 2,500 feet per second. Pyroxylin, by contrast, generated variable results that averaged 2,200 feet per second. These results, he claimed, were predicted by laboratory tests, and provided "equality (homogeneity of results) of shooting with this gunpowder," with "peerless homogeneity."[49] The homogeneity of results was true over time as well. Mendeleev's group found that pyrocollodion could be stored for three years in ordinary powder bags with little ballistic effect, and would store even longer in white india rubber or lacquered metal.[50] Likewise, it lasted for many hours at high temperatures during 6-inch shell experiments, surpassing Vieille's and Abel's rigorous gunpowder endurance tests even after years in storage.[51]

Of course, not everyone was happy with its performance. While Mendeleev's gunpowder was easy to produce and incredibly homogeneous under laboratory conditions, when it was produced in trial samples outside the laboratory it tended to grow a mold that dissipated its ballistic advantages. The problem was impure water, but it was difficult to generate sufficient distilled water in St. Petersburg, and instead they had to compromise and take water from the middle of the Neva river.[52] Furthermore, the army gunpowder engineers at Okhtenskii Armory were not at all pleased that Mendeleev was stealing their thunder—and their explosive, as they saw it. Particularly interesting about their objections is their almost unflinching acceptance of homogeneity—Mendeleev's formulation—as the relevant quality for a smokeless gunpowder. On 29 January 1894, the director of

48. Mendeleev to Chikhachev, June 1895, *MS*, vol. 9, 183. See also Mendeleev to Chikhachev, 5 May 1893, RGAVMF f. 421, op. 2, d. 821, ll. 134–39.

49. Mendeleev to Chikhachev, 5 May 1893, RGAVMF f. 421, op. 2, d. 821, ll. 134ob.–135; Mendeleev to Chikhachev, 18 June 1892, RGAVMF f. 421, op. 2, d. 768, l. 178. See also *MS*, vol. 9, 171.

50. RGAVMF f. 427, op. 2, d. 527, ll. 29–32.

51. RGAVMF f. 421, op. 2, d. 1233, l. 51. See also the letter to the Chief Inspector of Naval Artillery, 8 May 1895, RGAVMF f. 421, op. 31 ("art. chast'"), d. 41, 1895, l. 3, reproduced in Luk'ianov, "O neizvestnykh pis'makh D. I. Mendeleeva i arkhivnykh dokumentakh" (n. 33 above), 265.

52. "Zhurnal morskago tekhnicheskago komiteta po artillerii," 21 June 1895, RGAVMF f. 427, op. 2, d. 527, ll. 262–63.

Okhtenskii released an internal report that objected to the Mendelevian claim that the means of production at Okhtenskii "do not present any guarantee of achieving a product homogeneous and constant in chemical composition, and thus all the heterogeneous types of pyroxylin prepared at the factory are nothing other than a mixture of nitrocelluloses at different stages of nitration." Instead, they argued, pyrocollodion was just a particular type of pyroxylin. Mendeleev would find, they claimed, that factory conditions were qualitatively different than laboratory conditions, and thus pyrocollodion would fail when scaled up.[53] Admiral S. O. Makarov provided a substantial defense, going through Okhtenskii's results to argue that they were disingenuous about having produced a pyrocollodion-like powder in the past.[54] Okhtenskii aside, the vast majority of correspondence on pyrocollodion was effusively positive. The negative remarks and occasional mold seemed not to have tarnished pyrocollodion's stellar image. Meanwhile, Mendeleev continued to expound on yet more benefits of his powder.

The next was homogeneity of production, exactly the weak spot that Okhtenskii armorers had attacked. Identical pyrocollodion, it turned out, could be made independently of the form of starch used to generate the cellulose, whether "cotton or flax or hemp," and regardless of whether the acids (sulfuric and nitric) used to treat it were of slightly different concentrations than usual.[55] Mendeleev proposed radically simplified production; it was virtually impossible to run out of raw materials, and the process could even be performed by unskilled workers. If one had homogeneous production between batches, then the results of mixing shells would not lead to unfortunate detonations, as could occur with pyroxylin.[56] Thus Mendeleev began to extend the ideal of homogeneity from gunpowder itself to military procurement and production.

Smokeless-gunpowder production in Russia had only a short history when Mendeleev proposed pyrocollodion, but that history was one of remarkable growth. Pyroxylin began to be produced in St. Petersburg in 1880, and the production totals for the first seven years add up to a striking, almost eightfold, increase, topping out at 884 *pud* annually (1 *pud* = 36 pounds).[57] Over fifty thousand rubles a year were spent on generating more smokeless powder by the end of the decade, and in 1888 a military council set a goal for annual production goals of 2,140,000 *pud*. In the event, Russia did not meet that goal: production in 1900 was 1,324,079 *pud*, rising to 1,350,000 *pud* in 1903, all pyroxylin.[58]

Mendeleev disliked both the army's production facilities and state-led production. He felt that Okhtenskii was poorly constructed, since, copying France, easy access to sulfuric acid was not built into the factory design.[59] Instead, Mendeleev proposed decentralizing production to private chemical plants under a contract system. The particular plant he had in mind was P. K. Ushkov's, in Elagub.[60] "[O]nly upon complete failure of this approach," Mendeleev argued, should the navy "think of fulfilling the demand with state factories. In general it is desirable to have right away a combination of private and state factories."[61] Besides, the more private factories were involved, the lower costs would be, due to competitive bidding and the absence of administrative rigidities.[62] Pyrocollodion's simplified production process made this possible, and Mendeleev's close relations with both industrialists and bureaucratic decision makers (dating from his earlier

53. Vice Admiral Pilkin of the navy sent the report to Mendeleev on that same day and asked for Mendeleev's response as soon as his health improved: "Zhurnal komissii, obrazovannoi po prikazaniiu Nachal'nika Okhtenskikh porokhovykh zavodov, dlia razsmotreniia dokladnoi zapiski professora Mendeleeva, predstavlennoi Upravliaiushchemu Morskim ministerstvom," 29 January 1894, RGAVMF f. 421, op. 2, d. 879, ll. 84–86, quotation and Pilkin's handwritten referral both on 84. Mendeleev responded that Okhtenskii had never produced a homogeneous pyroxylin. Mendeleev to Chikhachev, 5 February 1894, RGAVMF f. 421, op. 2, d. 879, ll. 101–13.

54. S. O. Makarov, "O trudakh professora Mendeleeva i Nauchno-tekhnicheskoi laboratorii M. V. po vyrabotke tipa pushechnago bezdymnago porokha," 15 March 1894, RGAVMF f. 421, op. 2, d. 879, ll. 337–45.

55. Mendeleev to Chikhachev, 17 October 1892, RGAVMF f. 421, op. 2, d. 931, l. 2ob.

56. Mendeleev continued to argue this point even after he left the navy. See his letter to M. I. Dragomirov, 11 March 1899, quoted in A. Ia. Averbukh, "D. I. Mendeleev i sozdanie bezdymnogo porokha," *Voprosy Istorii Estestvoznaniia i Tekhniki*, no. 1 (1974): 51–54, on 52.

57. Luk'ianov, "O neizvestnykh pis'makh D. I. Mendeleeva i arkhivnykh dokumentakh" (n. 33 above), 260. For more detailed breakdowns, see Luk'ianov, *Istoriia khimicheskikh promyslov i khimicheskoi promyshlennosti Rossii* (n. 19 above), 324–55.

58. L. G. Beskrovnyi, *Armiia i flot Rossii v nachale XX v.: Ocherki voenno-ekonomicheskogo potentsiala* (Moscow, 1986), 105.

59. The French did not have to do this, since their factories were located near other acid-production sites. Vukolov (n. 16 above), 1538.

60. Ushkov, a graduate of Kazan University, was clearly Mendeleev's favorite for taking on pyrocollodion production. Mendeleev made several trips to Elagub to negotiate a contract, and Ushkov delivered on early samples before the navy canceled the orders. See RGAVMF f. 421, op. 2, d. 821, l. 133; f. 421, op. 2, d. 821, ll. 336–37; and the actual contract, which names Mendeleev as the official negotiator and liaison, f. 421, op. 2, d. 821, l. 509. Mendeleev repeatedly cited Ushkov in his economic writings as a good example of a chemical entrepreneur for a new Russia, and even wrote an obituary for him. See, for example, *MS*, vol. 9, 54 n. 1, 77, 86; *MS*, vol. 21, 318; *MS*, vol. 18, 243 and 296; *MS*, vol. 15, 630 (the obituary, dated 26 January 1898); and Mendeleev's chapter on the chemical industry in Departament Torgovli i Manufaktur Ministerstva Finansov, *Fabrichno-zavodskaia promyshlennost' i torgovlia Rossii. Vsemirnaia Kolumbova vystavka 1893 g. v Chikago* (St. Petersburg, 1893), 279. For Ushkov's biography, see G. S. Vozdvizhenskii, *Stranitsy iz istorii kazanskoi khimicheskoi shkoly* (Kazan, 1960), 21.

61. Mendeleev to Chikhachev, 5 May 1893, RGAVMF f. 421, op. 2, d. 821, ll. 134–39, on 137; *MS*, vol. 9, 53.

62. *MS*, vol. 9, 49. This proposal was similar to how cordite production was organized in England, which is helpfully analyzed in R. C. Trebilcock, "A 'Special Relationship': Government, Rearmament, and the Cordite Firms," *Economic History Review* 19 (1966): 364–79.

involvement with the Ministry of Finance) gave his comments additional weight.

OCTOBER
2003
VOL. 44

Mendeleev actually couched this partial privatization of gunpowder production in a proposal to overhaul the structure of armaments procurement. Before pyrocollodion or pyroxylin, production of traditional black powder for the Russian military was the province of the Russian Society for the Production and Sale of Gunpowder, a guild-like organization that essentially held a monopoly on military orders. The technical sophistication of smokeless powder and the need for chemical expertise precluded the society's involvement in production, and a new form of procurement was called for. Instead of modeling this on the acquisition of other military technologies by the navy, Mendeleev suggested a new procurement mechanism. Before the 1905 Revolution, the military rarely turned to private industry, and only new products such as smokeless gunpowder or light artillery could stimulate economic decentralization.[63] Mendeleev thought to combine private and state production: "[I]t would be best to combine private factories with state ones; without the first, one cannot establish a firm and profitable fundamental path of new production, and state factories, first of all, are already extant, and secondly, are useful for the direct contact of gunpowder affairs with military ones."[64] Furthermore, Mendeleev hoped, focusing on several large factories would provide a shock to the economy that would reinvigorate the chemical industry.[65] Here is the crux of Mendeleev's economic thinking: a proper coordination of the private and public sectors could bring benefit to both, and also produce a stable

63. Peter Gatrell, *Government, Industry and Rearmament in Russia, 1900–1914: The Last Argument of Tsarism* (Cambridge, 1994), 63 and chap. 6, "The Economics and Politics of Defence Procurement," which mostly focuses on the post-1905 period. On naval procurement after the Russo-Japanese War, see Gatrell, "After Tsushima: Economic and Administrative Aspects of Russian Naval Rearmament, 1905–1913," *Economic History Review* 43 (1990): 255–70, and "Defence Industries in Tsarist Russia, 1908–13: Production, Employment and Military Procurement," in *Economy and Society in Russia and the Soviet Union, 1860–1930: Essays for Olga Crisp*, ed. Linda Edmondson and Peter Waldron (New York, 1992), 131–51.

64. *MS*, vol. 9, 52 n. 2.

65. *MS*, vol. 9, 129. Had Mendeleev's plan been instituted, it would probably not have generated the desired results. As historian Jacob Kipp has noted in the case of rearmament with a screw-propelled navy, government devolution to private industry generated a hothouse effect, whereby private industry became dependent on the Imperial state's orders and thus lost the economic advantage. The newer the technology, the worse the effect, as seen in the cases of large maritime steam engines and heavy, rifled, breech-loading steel artillery. See Kipp, "The Russian Navy and the Problem of Technological Transfer: Technological Backwardness and Military-Industrial Development," in Eklof, Bushnell, and Zakharova (n. 26 above), 115–38, on 133. As one of the *T&C* referees pointed out, the state/private combination was similar to the naval construction methods employed in contemporary England and France. Mendeleev was almost certainly aware of the foreign examples.

network of individuals interested in preserving autocracy, which would in turn serve as a bulwark against cultural disintegration.

But before this could work, Mendeleev had to construct a homogeneous state. From the birth of the empire, the Russian army—clearly the dominant force in a land power—had clashed with the navy, that avatar of imperial arrogance created by Peter the Great. By the time Mendeleev appeared on the scene, the state had made a series of ineffectual attempts to resolve the conflict.[66] Mendeleev's plan for smoothing over difficulties centered, not surprisingly, on gunpowder. Since pyrocollodion would work for all weapon calibers, from the smallest to the largest, it could form the basis for rearmament of both branches of the armed forces. In the process, emergent mutual problems would generate discussion between the two, inevitably promoting unity.[67] Thus, the two armed forces would be forced by technology into dialogue, and this dialogue would in turn meld them, together with industry, into a powerful force able to impose Russia's united will on the wider world.[68]

Rejection: The Will against Technology

In 1893, Mendeleev's attention began to shift to his work at the Chief Bureau of Weights and Measures, and he could devote less time to lobbying for his gunpowder.[69] He continued as a consultant, however, until 26 October 1895, when he received a dismaying letter from the new minister of the navy, Pavel Tyrtov, stating that, "not touching on the principal question of the superiority of either pyrocollodion or pyroxylin gunpowders until the end of their comparative testing, the Ministry of the Navy has rushed in the present year to the services of Okhtenskii gunpowder factory for the most speedy supply of ships that are heading abroad with smokeless pyroxylin gunpowder."[70] Shortly afterward, on 4 December, Mendeleev retired from navy service.[71] The navy still asked his advice, however. On 5 December 1901, it inquired how he felt about the potential closing of the navy's inde-

66. L. G. Beskrovnyi, *Russkoe voennoe iskusstvo XIX v.* (Moscow, 1974), 356; G. P. Meshcheriakov, *Russkaia voennaia mysl' v XIX v.* (Moscow, 1973), 258–59.

67. Note by A. Brink on the margin of Chel'tsov's letter to the Chief Inspector of Naval Artillery, 5 April 1893, RGAVMF f. 421, op. 2, d. 821, l. 52: "These questions [of storage] are very important and I consider it helpful to discuss them together with the Army. . . ." See also Mendeleev to Chikhachev, 5 May 1893, RGAVMF f. 421, op. 2, d. 821, l. 135; and *MS*, vol. 9, 159 on uniting both forces with a joint laboratory.

68. *MS*, vol. 9, 58.

69. Michael D. Gordin, "Making Newtons: Mendeleev, Metrology, and the Chemical Ether," *Ambix* 45 (1998): 96–115; and Nathan M. Brooks, "Mendeleev and Metrology," *Ambix* 45 (1998): 116–28.

70. RGAVMF f. 427, op. 2, d. 527, l. 409.

71. On Mendeleev's activities after leaving the navy, see Gordin, "The Ordered Society and Its Enemies" (n. 21 above), 437–38.

pendent smokeless powder factory. He responded three days later: "This invention [smokeless powder] . . . is gradually proliferating . . . abroad . . . and the preservation of a small factory of the Navy for the preparation of an explosive substance is very useful for the defense of the state, and one could wish for the expansion of the activity of this factory. . . . The expense demanded for the content of the small naval factory should be considered infinitesimal. And as this infinitesimal expense is connected with autonomous Russian progress in the matter of explosive substances, then I consider the closing of the Naval factory premature."[72]

Although Mendeleev still lobbied for resumed comparative testing, which he secured by writing directly to the minister of war, M. I. Dragomirov, the disastrous Russo-Japanese War (1904–5) consumed all experimental quantities, and by 1909 the navy's pyrocollodion factory was shut down "for lack of economy." In 1913, six years after Mendeleev's death, the issue arose once more, as one of Russia's largest gunpowder manufacturers insisted that "it appears desirable again to discuss the question of whether we ought not to prepare our weapons-grade gunpowder from pyrocollodion; at the present time such a discussion could flow peacefully, without offending professional vanity."[73]

Many explanations have been offered for this rejection. Some have suggested that it was impossible to make pyrocollodion at a competitive price by the time of the Russo-Japanese War, or that the army-navy conflict was involved.[74] The argument from economy is contradicted by the success of the Americans in producing pyrocollodion (see below) and by contemporary data, which showed no decisive advantage for pyroxylin. On the other hand, the army-navy conflict was obviously a concern, as demonstrated by Mendeleev's own attempts to bridge it, but it can hardly have been a decisive reason why the navy would not adopt its own powder. A more likely explanation, offered by Mendeleev's former student S. P. Vukolov, a long-term employee at the Scientific-Technical Laboratory, is that there were concerns about Mendeleev's civilian status:

> In the eyes of those who then moved the gunpowder affairs of the army artillery, D. I. [Mendeleev] had one large disadvantage: he was a civilian (*shtatskii*) man, not a military one, not having a degree from a high artillery school. They could not stomach it when this man, alien to their environment, spoke with all the heat of his fervent nature about the burning of gunpowder in the barrel of a weapon, or the reasons for abnormal pressures upon firing, leading to the firearm's explosion, when he spoke of the inadequacies of their gunpowder (the gunpowder of the French), pointing to the homogeneity, the limit of pyrocollodion powder.[75]

Even granting aspects of this sociological explanation, I suggest that there was also a cultural component to the story. Mendeleev deliberately targeted a particular faction within the military—technological determinists whom he perceived as rising in the military hierarchy—that was in fact losing power temporarily in the hiatus between Nicholas II's coronation (1894) and the onset of the Russo-Japanese War. This single-mindedness was part of the reason why pyrocollodion failed to gain acceptance.

As Elting Morison has shown in his classic study of the prolonged delays by U.S. Navy in adopting continuous-aim firing, militaries in general are resistant to technological innovations that might alter their stable and highly structured social dynamics.[76] Such reluctance is apparent in the firearms revolution in Russia. In both cases, a broader set of social concerns mitigated against the technically superior choice. Yet Mendeleev often promoted the virtues of his gunpowder as if technical qualities were the only important criteria.[77] It would be ahistorical to call Mendeleev a technological determinist, but he firmly held to the view that in warfare technical capabilities would always prove decisive. At that very moment, however, Russian military theorists were engaged in heated debates over precisely the question of the relative importance (or lack thereof) of technical superiority, a debate that directly applied to the introduction of smokeless powders.[78]

Mendeleev sided with the military proponents of modern technology. In the 1880s and 1890s, a reformulation of military tactics and strategy in Russia had begun, for the most part evaluating the consequences of the

72. Quoted in T. S. Kudriavtseva, "Novye dannye ob issledovaniiakh D. I. Mendeleeva v oblasti porokhodeliia," in *Materialy po istorii otechestvennoi khimii*, ed. N. A. Figurovskii et al. (Moscow, 1953), 234–241, on 241. Ellipses in Kudriavtseva.

73. Quoted in Vukolov (n. 16 above), 1538; Averbukh, "D. I. Mendeleev i sozdanie bezdymnogo porokha" (n. 56 above), 54.

74. Luk'ianov, "O neizvestnykh pis'makh D. I. Mendeleeva i arkhivnykh dokumentakh" (n. 33 above), 268; and Vernidub (n. 13 above), 399.

75. Vukolov, 1537. Mendeleev was not a complete military outsider. Perhaps unbeknownst to Vukolov, he had taught courses at the Nikolaevskii military academy and to the Cadet corps. See L. G. Beskrovnyi, *Russkaia armiia i flot v XIX veke: Voenno-ekonomicheskii potentsial Rossii* (Moscow, 1986), 192. Vukolov's comments also point to Mendeleev's at times prickly personality, which repeatedly caused problems for his career.

76. Elting Morison, *Men, Machines, and Modern Times* (Cambridge, Mass., 1966), chap. 2.

77. For an example, see *MS*, vol. 25, 444. Mendeleev's employee at the laboratory, P. P. Rybtsov, echoed that view in 1907, showing the persistence of such rhetoric; Rybtsov (n. 39 above), 152. This was quite common practice among contemporary gunpowder scientists. For example, Frederick Abel commented that smokeless powder "can scarcely fail to change more or less radically many of the existing conditions under which engagements are fought"; Abel (n. 9 above), 355.

78. Navy officers frequently used the language of technical autonomy. See D. Fillipov on new ships' motors, RGAVMF f. 421, op. 2, d. 1522, ll. 21–64, esp. 50ob. On the debates over smokeless gunpowder, see Meshcheriakov (n. 66 above), 267.

reforms of the 1860s and 1870s. Military theorists split into two schools: the "academics," who adhered to the classic texts of military strategy, such as Clausewitz, and the "Russian school," which turned to archives and applied new historical methodologies to uncovering how the timeless laws of strategy were worked out in the concrete instances of Russia's wars.[79] One of the few theorists from this "Russian" camp to address the implications of smokeless powder was N. P. Mikhnevich. Smokeless gunpowder, he was convinced, would on its own alter the structure of warfare: "The lessening of gunpowder smoke should influence the distribution and use of weapons in battle, and consequently the battle order and the battle itself, and consequently also the most important divisions of applied tactics."[80] Had students trained under Mikhnevich's doctrines been making the decision over pyrocollodion in 1895, perhaps Mendeleev's gunpowder would have fared better.

The very concept that technology could or should have the determining role on the battlefield was precisely what was at issue in the army and navy hierarchies at this time. The first wave of modernization that had spurred smokeless gunpowder research had ended, and as the 1890s progressed different types of "modernizations" were under evaluation. M. I. Dragomirov had been elevated to the head of the Ministry of War, and he led a faction of strategic thinkers that emphasized individual bravery on the field of battle over technological gadgetry. As Dragomirov perceived it, man was torn between two opposite impulses: self-preservation and self-sacrifice, correlated with the intellect and the will, respectively. The former went with gunpowder and firearms, the latter with bayonets. In any battle, while firepower would set up the forces of attack and defense, in the end technology would stalemate, and a particular act of will would be required to break that deadlock.[81] In other words, no war could be won without a bayonet charge, and placing one's reliance on technological improvements would lead nowhere, since technological arms races always ended in a tie. He objected to overconfidence in the ability of technology alone to resolve military conflicts. In late-nineteenth-century Russia, Dragomirov's theoretical position carried a lot of intellectual weight beyond his manifest political resources. There was good reason in the 1890s to be skeptical of firepower's decisive role, and hence dubious about the value of increased muzzle velocities. The fiscal stinginess that limited bullets for training and the lack of adequate instruction made it difficult to see the payoff of expensive technical innovations. And in the anti-intellectual climate that prevailed in military thought, one could point to the way Russian soldiers held up bravely under fire in the battles against Turkey in 1877–78 to argue that Dragomirov was right: will did trump intellect in war.[82] As long as the military had a workable, if imperfect, smokeless gunpowder in pyroxylin, there seemed no need to spend more funds and institute more changes on the principle that technology must advance inexorably, when it was precisely that change that one was trying to control.

Mendeleev's pyrocollodion may have foundered on the rocks of Dragomirov's volitional philosophy, but its story did not end in total obscurity. Ironically, the U.S. Navy adopted pyrocollodion by 1900. Russia's naval agent in the United States, Major General D. F. Mertvyi, wrote to the General Naval Staff on 15 September 1899 that the United States seemed to have solved the problem of an adequate naval powder: "Rear Admiral O'Neill informed me that at the present time the Nor. American fleet has full reserves of smokeless gunpowder. The working out of the recipe of this gunpowder was carried out on the basis of the printed researches into the question by Professor Mendeleev. It turns out that there was in the American navy a Lieutenant Bernadou who knows Russian and at the same time gave himself up to chemical researches. This dual quality of Bernadou . . . was used and the navy worked out for itself a satisfactory smokeless gunpowder."[83]

Mendeleev was aware of Bernadou's research and did not discourage it; in fact, on 14 November 1900 the American consul in St. Petersburg, W. R. Holloway, told Mendeleev that one S. L. Meyers from Chicago was interested in studying Russian smokeless powder and wanted samples sent to him. Mendeleev had an associate, F. I. Blumbach, direct him to published articles.[84] He did the same in response to a request for information from Mary Baté of St. Catherine's School in Ontario, Canada.[85] Mendeleev's gun-

79. Meshcheriakov, 232–44; Menning (n. 9 above), 125; von Wahlde (n. 23 above), 61–63; Beskrovnyi, *Russkoe voennoe iskusstvo XIX v.* (n. 66 above), passim; and V. D'iakov, "O razvitii russkoi voenno-istoricheskoi mysli v poslednei chetverti XIX veka," *Voenno-Istoricheskii Zhurnal* 5 (1959): 60–72.

80. N. P. Mikhnevich, "Taktika i ee evoliutsiia v zavisimosti ot uslovii komplektovaniia voisk i tekhnicheskikh izobretenii dannoi epokhi," in *Russkaia voenno-teoreticheskaia mysl' XIX i nachala XX vekov*, ed. L. G. Beskrovnyi (Moscow, 1960), 441–51, on 444; see also the excerpt from Mikhnevich's most important discussion of gunpowder, "Vliianie noveishikh tekhnicheskikh izobretenii na taktiku voisk," 415–40. A substantial portion of this document discusses the exact changes smokeless powder would bring about on the battlefield. By the end of the nineteenth century, the Nikolaevskii academy had switched to Mikhnevich's textbook on strategy, *Istoriia voennago iskusstva s drevneishikh vremen do nachala deviatnadtsatago stoletiia* (St. Petersburg, 1896). Summaries in English of Mikhnevich's thought can be found in Van Dyke (n. 26 above), 117–18, and Menning, 132.

81. M. Dragomirov, "Uchebnik taktiki," in Beskrovnyi, *Russkaia voenno-teoreticheskaia mysl'*, 339–47; Menning, 39. Compare this with the contemporary French doctrine of the role of *élan* in determining the outcome of conflicts. See Richard D. Challener, *The French Theory of the Nation in Arms, 1866–1939* (New York, 1955).

82. Menning, 85; Bradley (n. 25 above), 124; Kenez (n. 23 above), 124.

83. RGAVMF f. 417, op. 1, d. 1967, l. 160. Bernadou often stressed how he worked out his gunpowder independently from Mendeleev at the Naval Torpedo Station at Newport, Rhode Island, in 1895–1896. Bernadou (n. 9 above), 28, 174 n. Claims of treachery or espionage are clearly unfounded.

84. Dmitriev (n. 10 above), 139.

85. She wrote to Mendeleev on 26 December 1899 (N.S.), "Will you kindly tell me

powder, begun with journey from East to West, had finally made the journey on its own.

Untypically for the history of military technology, then, Mendeleev's smokeless powder successfully made the difficult transition from laboratory to field, and failed because of his own aggressive strategy of selling pyrocollodion as a decisive technology—a consequence of specific local dynamics in the context of late-imperial Russia's modernizations. His efforts to develop and market his smokeless gunpowder in the intricate political climate of the St. Petersburg military hierarchy left almost no trace, either historical or historiographical. His work has been examined by a small group of specialists over the years, but their findings have done little to reconceptualize the career of Russia's most famous chemist. Historians of gunpowder technology in the West, on the other hand, have taken almost no note of Mendeleev's ventures, even though his approach was developed through numerous mutual interactions over several years with Abel, Vieille, and the other principals of smokeless powder research. And Mendeleev's powder left no direct historical descendants, if only because of its replication and subsequent dissemination in more favorable climes. Most tragically for the man himself, the vision of homogeneity as the central feature of a completely modernized and rational imperial military came to naught as that military—and the larger empire—broke apart on the shoals of the will.

the name of the smokeless gunpowder which you invented in 1896 and its advantages over other high explosives?" Mendeleev's polite response in English on 28 January 1900 (N.S.) was to tell her to look it up in *Morskoi Sbornik*, reprints of which he was unable to send her. ADIM II-A-52-2-B.