Science in Context

http://journals.cambridge.org/SIC

The Great War, the Russian Civil War, and the Invention of Big Science

Alexei Kojevnikov

Science in Context / Volume 15 / Issue 02 / June 2002, pp 239 - 275
DOI: 10.1017/S0269889702000443, Published online: 14 January 2003

Link to this article: http://journals.cambridge.org/abstract_S0269889702000443

How to cite this article:
Alexei Kojevnikov (2002). The Great War, the Russian Civil War, and the Invention of Big Science. Science in Context, 15, pp 239-275 doi:10.1017/S0269889702000443

Science in Context **15**(2), 239–275 (2002). Copyright © Cambridge University Press
DOI: 10.1017/S0269889702000443 Printed in the United Kingdom

The Great War, the Russian Civil War, and the Invention of Big Science

Alexei Kojevnikov

Department of History, University of Georgia, Athens, Georgia.
Institute of the History of Science and Technology of the Academy of Sciences, Moscow.
E-mail: anikov@arches.uga.edu

Argument

The revolutionary transformation in Russian science toward the Soviet model of research started even before the revolution of 1917. It was triggered by the crisis of World War I, in response to which Russian academics proposed radical changes in the goals and infrastructure of the country's scientific effort. Their drafts envisioned the recognition of science as a profession separate from teaching, the creation of research institutes, and the turn toward practical, applied research linked to the military and industrial needs of the nation. The political revolution and especially the Bolshevik government that shared or appropriated many of the same views on science, helped these reforms materialize during the subsequent Civil War. By 1921, the foundation of a novel system of research and development became established, which in its most essential characteristics was similar to the U.S. later phenomenon known as "big science."

Those who watched Russian industry perform during the first months of the Great European War could not escape the conclusion that the country's degree of economic, industrial, and scientific dependence upon Germany was intolerable and bordered on the colonial. This situation should not have been surprising in high technology fields, such as machines and chemicals, where less than 50 per cent of the needed products were manufactured in Russia (Grinevetskiy 1922, 33). But even in industries that could have relied entirely on native materials and supplies, some essential parts had to be imported. Once the border with Germany closed in August 1914, chaos ensued in Russian industry, which was unable to find or quickly produce substitutes for previously imported goods. Shocked by this discovery, some observers even suspected a pre-war German conspiracy behind this arrangement (Novorusskiy 1915). Although diplomats had been expecting a future showdown with the Central powers for years, no plans for the wartime mobilization of industry had been prepared. The crisis and shortages at the start of the war made many in Russia – as in other countries – envy the German war-oriented management of industries and demand centralized and rational planning of the economy several years before this principle would be declared "socialist" by the revolutionary Bolshevik government.[1]

Foreign investors dominated Russian civilian industry, which consequently relied on imported technologies and know-how rather than on independent research and expertise. Military industry and major munitions factories were owned by the state, yet even in this field which was traditionally the government's concern, the prevailing strategy had been to buy and copy foreign innovations. In the judgment of an economic historian, while some of these factories "yielded to no one in the quality of their product and stood the test of international comparison and competition . . . there is no sign that the state sector was the locus of technical innovation or innovation in management style" (Gatrell 1994, 258). Putilov, Obukhov, and Okhta military factories established modest laboratory facilities during the war, but they were used primarily for routine control of production (Bastrakova 1973, 45). General A. A. Manikovskiy, who during the war was responsible for the equipment of the Russian army, could only complain that "Germany had supplied the entire world, including Russia, with the tools of war, and we had paid our money for the development of expensive German military industry" (Manikovskiy 1920, 237).

Once the war broke out, the military followed its traditional instincts and turned to allies and neutrals with requests for supplies and technology. Hastily, Manikovskiy tried to place orders for military equipment in Japan and the USA, which resulted in huge expenditures and limited satisfaction. A year later, he came to consider those purchases a mistake and to think that much better results could have been achieved had the resources been directed to the development of native industrial production from the very beginning of the war: "After having spent more than 300 million rubles on foreign automobiles, we now [November 1915] came to the decision to develop our own manufacturing" (Manikovskiy 1920, 248). Military officials also gradually recognized the need to develop or greatly expand the production of aircraft, chemicals, radios, optical devices, and other war-related products requiring advanced knowledge and expertise.

The war brought profound changes to Russian science as well. It broke scientific communications and contacts with colleagues from belligerent nations, resulting in virtual scientific isolation that lasted about six years, until the end of the Civil War in 1920. No other problem of that period – not even enormous economic and political hardships – caused as many complaints among Russian scientists, but none contributed so much to the development of their identity as a national community. Whereas before the war, most Russian research was published in foreign and foreign-language periodicals, the war years saw an upsurge in the number of national scientific societies and Russian-language academic journals (Aleksandrov 1996).

Perhaps even more importantly, the war crisis led to a major shift in attitudes toward research and its goals. In the preceding two or three decades – marked by ever

[1] See Bukshpan 1929 for the analysis and comparison of mobilization-style economies in Germany, Russia, and other belligerent countries during the Great War.

increasing nationalistic and imperialist competition between major powers – the prevailing motivation among Russian academic researchers was to catch up with their European colleagues in contributions to the world's body of knowledge in "pure" sciences, all the while demonstrating sometimes benign, but mostly arrogant neglect of practical, "applied" research. Although similar attitudes were common in many other European countries, in fin-de-siècle Russia the ideology of pure science was taken much more seriously and literally.[2] After all, industry offered practically no career opportunities for Russian scientists, and the only available jobs for them, with very few exceptions, existed at universities and other teaching institutions. The war changed the motivations and values of researchers most dramatically: even university-based scientists started searching for practical and military applications of their knowledge and establishing links with industry.

Relatively little could be accomplished in the course of the war itself to compensate for the almost total absence of such links previously. Yet the exposed inadequacy at the time of a major national crisis stimulated plans and activities toward the reform of Russian science. The reform implied, in its major trends, the creation of a national network of specialized institutions for research proper rather than teaching; a major reorientation towards research goals related to the nation's practical needs; and a preference for large interdisciplinary projects with collectives of researchers and engineers engaged together in the simultaneous production of advanced knowledge and technology. The first blueprints for such reforms were drafted by Russian scientists in response to the experience of the World War; they were subsequently adopted, endorsed, and adapted by the revolutionary government during the years of the Civil War. As the international isolation of Russian science eased in 1921, the foundation of a novel government-sponsored institutional system of research and development with a characteristic pattern of a "symbiosis, . . . a fusion of 'pure' science, technology, and engineering" – which several decades later would receive the name "big science" (Pestre and Krige 1992, 93) – was already in place.

The period of World War I has hitherto received undeservedly little attention in the history of Russian science and in the history of Russia in general – as compared to the histories of other European countries – because it was overshadowed in perceived importance by the subsequent great revolution. To summarize the results achieved by the Russian Empire, one typically chooses 1913, the last year of peace, while the new society is seen as starting with the revolution of 1917; the intermediate war is generally viewed as a disintegration leading to a disgraceful end rather than as an emergence of something importantly new. This study – along with several other recent works – reconsiders the prevailing stereotype. The Great War is seen here as a beginning rather than an end, or, more precisely, the new Soviet society, in many of its essential features, appears to have been born during a period of permanent war –

[2] On the ideology and praxis of scientists in a different national context, see Edgerton 1996.

1914 to 1921 – and to have retained for at least several decades some of the birthmarks acquired during this process.[3]

1. Science, Industry, and Military in the Late Russian Empire

"I don't think it is dishonorable for a Russian professor of chemistry to work in the applied direction," Vladimir Markovnikov of Moscow University defended himself in 1901. Despite the common recognition that chemistry was industrially and economically the most important scientific discipline of the late nineteenth century, Russian academic chemists took pride in working on "pure" topics. Even though Markovnikov's investigations of the chemical composition of petroleum from Caucasus oil fields had led him to discover important new classes of organic substances, they still deviated from the accepted norm and required a special apology (Solov'ëv 1985, 310).

Markovnikov had been drawn into studies of Russian oil by chance twenty years earlier, through an invitation to review the state of the country's chemical industry. As no direct industrial statistics were available, he analyzed the existing data on foreign trade and concluded that national industry was capable of producing only the most primitive of chemicals, while almost all products that required special chemical knowledge or expertise were imported from abroad. The rapidly developing Moscow textile industry, in particular, depended on imports of not only synthetic dyes, but even of soda, from Germany. It was the "fate of all nations who are culturally less developed than others" to be economically disadvantaged when new artificial products are developed in more advanced countries, warned Markovnikov in his public lecture, "Modern Chemistry and the Russian Chemical Industry." Having concluded that "one can hardly expect from Russian industry any stimulus for the development of chemistry in Russia," he argued in favor of protectionist tariffs to encourage the production of more sophisticated chemicals (Markovnikov [1879] 1955, 646, 666). After the lecture, Markovnikov was approached by the entrepreneur V. I. Ragozin, who offered financial support for a research project on petroleum from Baku.

In contrast with the sorry state of the chemical industry, academic research in chemistry – as well as in mathematics and physiology – achieved a high level of development in late Imperial Russia. By the end of the century, most universities and engineering schools equipped advanced chemical laboratories for their professors' research (Lomonosovskiy 1901). In Markovnikov's judgment, Russian chemists were "sometimes ahead of others," even though their studies had a "predominantly

[3] A similar approach has also been developed in Holquist 1997; and Hoffmann and Holquist, forthcoming. With regard to science, Nathan Brooks (1992, 360) has already noted that "for chemists, the period from World War I through the early years of the Soviet regime was one of relative continuity, not discontinuity." Several recent books indicate the rise of historical interest towards the role of World War I in Russian history (Pisarev and Mal'kov 1994; Mal'kov 1998; Smirnov 1999).

theoretical character." His observation resembled typical British complaints of the time: the Russian chemist Nikolay Zinin discovered how to synthesize anilin, which was then used by the British chemist William Perkin to synthesize the first artificial dyestuff, but it was Germany that took all the profits from monopolizing the world's industrial application of these discoveries. Markovnikov complained further that Russian industry suffered from a severe shortage of qualified technicians, but had no jobs to offer chemists with a university diploma (Markovnikov [1879] 1955, 642, 648).

Even Markovnikov, however, paid tribute to the common cult of his Russian and German peers by insisting that university instruction in chemistry should deviate in no way from the strict norms of pure science, lest its level be compromised. He waited for industry to become sophisticated enough to engage in a useful interaction with academic science, rather than allowing science to step down from its pedestal (Markovnikov [1879] 1955, 672–675). Twenty years later, around 1900, the debate was still alive in Russia on whether the country should industrialize or remain agricultural, even though industrialization was already developing apace with foreign capital and imported technologies, but without a single advanced industrial laboratory or any significant contact with academic science at the universities. Markovnikov's research on applied topics remained, as before, a controversial exception to the dominant attitudes among his colleagues. Russian academic chemists enjoyed a great international reputation, and petroleum exports were rising rapidly, but the chemical industry constituted a pitiful 2.1 per cent of the country's total industrial production (Kovalevskiy 1900, 242).

A rather unique exception from the prevailing norm was Dmitriy Mendeleev (Mendeleyev), Markovnikov's colleague from St. Petersburg, famous for his invention of the periodic table of chemical elements. A very unconventional academic, Mendeleev ventured far outside his special field of inorganic chemistry, publishing and advising government officials and private individuals on various matters of industrial production, metrology, technology, economics, foreign trade – where he also favored and helped introduce protectionist tariffs – and politics. Even more unusual for a university professor, Mendeleev also did some important research for the military. I. M. Chel'tsov, chemistry professor at the School of Mine Officers in St. Petersburg, asked him to help the Russian Navy discover the secret of the latest French invention, smokeless gunpowder. Hoping to learn some secrets from the Allies, Mendeleev undertook a special trip to France and Britain, reporting afterwards that the French did not want to share much, while the British were more open but their powder was no good. Yet what little he had learned enabled Mendeleev to start experiments in his university laboratory and eventually to offer the Navy his own version of smokeless gunpowder, together with a piece of advice:

> The safe and timely achievement of the goal of providing the Russian Navy with appropriate types of smokeless gunpowder is possible only with the help of an independent scientific and practical study of the problem in Russia, whereby all details

> would have to be developed by us ourselves, and the appropriate temporary secrecy maintained at the level with which similar activities are pursued in England, France, and Germany. (Dmitriyev 1996, 137)

The Navy agreed to establish a Scientific-Technical Laboratory in 1891, with which Mendeleev was affiliated until 1895, yet his efforts proved abortive. Mendeleev's version of smokeless gunpowder was tested in 1893, but the rivalry between the Navy and the War ministries impeded its full-scale industrial production (Gordin 2001, ch.7). By the time of Mendeleev's death in 1907, the project had been abandoned for at least three years, for which Russia paid dearly during the Great War. As for the War Ministry, it did not have any research facility until December 1914 – several months into the full-scale European war – when it established its own Central Scientific-Technical Laboratory (Nauka 1920, 117–118).

The situation with research at military schools was not much further advanced. As a young officer studying at the Grand Duke Mikhail Artillery Academy in St. Petersburg, Vladimir Ipatieff (Ipat'ev) nourished aspirations to become a chemist. Among his Academy professors was one famous scholar – metallurgist Dmitriy Chernov – who had made fundamental discoveries in the fields of steel production and gun manufacturing, but teaching and occasional consulting rather than original research occupied the rest of the faculty. As there was no chemical laboratory to speak of, Ipatieff assembled a small private laboratory in his apartment. Upon graduation in 1892, he became the Academy's instructor in chemistry and – in order to produce a dissertation necessary for promotion to the professorial rank – attended a laboratory at St. Petersburg University. Ipatieff's request for funding at the Artillery Academy was initially turned down by a superior, who

> explained in a soft, insinuating voice, with which he was used to overruling his opponents, why the chemical laboratory never received more than half of its allotted money. . . . He said there was no reason why the Academy should appropriate money for a laboratory which had not produced a single scientific investigation in ten years and whose only published dissertation did not describe a single experiment. (Ipatieff 1946, 59, 102–109)

Only after Ipatieff had defended his dissertation and been promoted in 1899 to become the Academy's first Professor of Chemistry and Explosives did he manage to organize the chemical laboratory properly. There he soon discovered a new class of catalytic organic reactions occurring under high temperatures with iron as a catalyst, which brought him recognition and fame in the academic world and opened the way toward his subsequent groundbreaking studies of chemical catalysis. Even though he taught at a military school and rose to the rank of general by 1910, Ipatieff regarded his laboratory research as "pure organic chemistry," made little if any effort to put his discoveries to military or civilian use, and blamed industry for the lack of interest:

> Unfortunately, the Russian chemical industry was too immature to use the scientific discoveries even then available. I still did not bother to take out patents, and once told one of my friends that I was a scientist and wanted complete freedom in my work, which I would not have if I had to be concerned with patents. Had I been a German chemist, I should probably have been infected by the same patent disease as were others. The German chemical industry made full use of my data at no cost to itself. (Ipatieff 1946, 174, 178)

Ipatieff recalled that his attitude toward industrial applications started changing in 1913, after a German engineer took a patent right on his discoveries. A major shift in his understanding of what it was to be a scientist, however, occurred due to the Great War. The extreme lack of shells was considered the major cause of the Russian Army's difficulties during the first year of the war. To deal with the problem, the Chief Artillery Administration established a commission for the procurement of munitions. The commission started its work with arranging for major purchases of toluen and crude benzol abroad, primarily in the United States, rather than developing their manufacture in Russia. "The mood in general" – recalled Ipatieff – "was one of pessimism with a lack of confidence in our own forces and a feeling of inferiority in the face of German technology" (Ipatieff 1946, 196). That initial decision was regretted and reversed in 1915, when the commission ordered the construction of the first state benzol plant in the Donets coal basin. The plant started producing in September 1915 and was followed immediately by the construction of some twenty more state and private factories and by further work on the production of other war-needed chemicals: benzene, toluen, trotyl, and xylene.[4]

On 26 January 1915 professor-chemist and General A. A. Zabudskiy, the commander of the newly created Central Scientific-Technical Laboratory of the army, called a meeting to discuss the technical component of the war. Besides other topics, the meeting briefly considered the use of "suffocating and intoxicating gases in shells," which the majority of officers opposed, arguing that "such methods can be regarded as inhuman and have not been previously used by the Russian army." Still, Zabudskiy did not completely rule out possible future uses of poison gases, "in case of the enemy's gross abuse of such methods." He ordered the laboratory's department of powder and explosives to conduct research on appropriate substances in order to be ready "in case of an emergency, to start production."[5] The emergency was not long in coming: in late May 1915, one month after the first massive attack with poison gas on the Western front, the Germans used chemical weapons also in the East, at Rawka near Warsaw, causing the Russian army about 9,000 casualties, more than 1,000 of

[4] On the "shell crisis" and attempts to purchase materials abroad, see Stone 1975, ch. 7. On the wartime production, see Ipatieff 1946 and "Materialy o nalichii proizvodstva i rasshirenii proizvodstva vzryvchatykh veshchestv i promezhutochnykh produktov, 1915" Voyenno-istoricheskiy arkhiv, Moscow (hereafter VIA), f. 507, op. 2, d. 37.

[5] Zabudskiy to the Secretary of the General Staff M. A. Belyayev, 29 January 1915. VIA f. 507, op. 3 d. 192, pp. 1–2.

which were fatalities. Only then did the Chief Artillery Administration organize a special Commission on Poison Gases, for the production of liquid chlorine, phosgene and other gases for use in shells (Haber 1986, 36–39; Ipatieff 1946, 197–215).

The commissions on explosives and on poison gases merged in 1916 to form the Chemical Committee, which later added three more departments: Incendiaries and Flame Throwers, Gas Masks, and Acids. The first tests of shells filled with chlorine took place in June 1915. Industrial production of chlorine started in early 1916, and of phosgene later that year. The committee decided to abstain from using cyanide-containing substances unless the Germans used them first, but went ahead with producing chloropicrin – tear gas – and a few other chemicals.[6] Driven by the huge military demand, Russian industrial production swelled during the war years (Gatrell 1986, 185). Employment in the chemical industry rose between 1913 and 1917 from 33,000 to 117,000 workers (Strumilin 1935). The crisis with the production of explosives and shells was resolved, at least partly, in 1916 (Barsukov 1938, 351). Hundreds of tons of poisonous chemicals were also produced, but, according to the available statistics, by April 1917, most of them remained at storage and production sites, with only the miniscule amount of 138 puds (just over 2 tons) of liquid chlorine actually delivered to the front.[7] It thus does not seem likely that the already decaying Russian army had a good chance of using any substantial amount of chemical weapons.

While Ipatieff and his military peers at the Chemical Committee were building and mobilizing the chemical industry, civilian chemists started searching for ways to make their contributions to the war effort.[8] Aleksei Chichibabin, chemistry professor at Moscow Higher Technological School, published newspaper appeals to chemists, inviting them to join research on medicaments, and to industrialists, arguing that in order to achieve economic independence from Germany, "The Russian chemical industry, from the very beginning, must find its basis in Russian science . . . and take care of the establishment of most favorable conditions for the quickest and widest development of Russian chemical science" (Chichibabin 1914; 1915). Chichibabin put his laboratory to work on alkaloids for the needs of the pharmaceutical industry and started developing methods for the production of opium, codeine, morphine, aspirin, and other medicaments, the importation of which stopped during the war. About 30 volunteers – chemists and chemistry students – joined him in this effort, and in March 1916 the Council of Ministers approved the establishment of an experimental pharmaceutical factory adjacent to the Moscow Higher Technological School for the production of war medicaments (Yevteyeva 1958, 332–334).

[6] "Pervyye ispytaniya snaryada s khlorom, 11–12.6.1915," VIA, f. 507, op. 3, d. 192, pp. 43–44; "Khod rabot komissii po zagotovke udushlivykh sredstv, 1915–1916" VIA, f. 507, op. 3, d. 1, p. 26; "Doklady o khode rabot komissii po zagotovleniyu udushayushchikh sredstv, 1915–1917," VIA, f. 507, op. 3, d. 2.

[7] For the statistical data on Russian production of war-related chemicals in 1916–1917, see Bukshpan 1929, 362–366. For the data on production and deliveries of suffocating substances, see "Perepiska i doneseniya ob izgotovlenii i perevozkakh udushayushchikh sredstv, 1915–1917," VIA, f. 504, op. 16, d. 20, p. 590.

[8] For more on Russian chemistry and the war, see Brooks 1997.

Probably the biggest single contribution by a Russian academic scientist to the war effort came from Ipatieff's scientific rival, Nikolay Zelinskiy of Moscow University. In 1915 Zelinskiy started working on the so-called "passive chemical warfare," by the fall of the same year proposed using activated charcoal for protection against poison gases and developed appropriate chemical methods for the required activation (Zelinskiy and Sadikov 1918; [1941] 1960). Engineer Eduard L. Kummant designed a special rubber mask with a container for charcoal, and the manufacturing of the Kummant-Zelinskiy mask started in 1916, despite delays caused by red tape and rivalry with other inventors. By the end of the war, Russia had produced some 15 million gas masks of several different types (Ipatieff 1946, 218–235; Nametkin 1954, 11).[9]

However important this particular invention was, it started paying off only in 1917, when the country's determination and willingness to wage war was already collapsing. Overall, the degree of involvement of Russian scientists in the war hardly matched that of their German, British, and French peers.[10] Institutionally and as a community, Russian science came to the situation of national emergency unprepared. With no pre-existing working relationship with either military or civilian industry, even the available scientific expertise and potential could not be used effectively. Connections had to be established in the course of the war itself, which took time and started delivering modest results only toward the end of the war. In contrast, the Russian scientists' response to the inadequacies revealed by the war and their public outcry for major reforms were anything but modest.

2. The Idea of Research Institutes

In an Empire pregnant with revolution, many monarchists and conservatives were looking forward to progressive change, while those who under normal conditions would be called moderates held radicalism in high fashion. Even many representatives of the noble and wealthy classes developed a distaste for half-measures and piecemeal, compromise solutions, preferring, at least in posture, tear-downs to add-ons, revolution to reform. The spectrum of proposals for social change favored by Russians reflected many common international trends of the early twentieth century, but tended to be more radical in demands, more uncompromising in tone, and more urgent in time schedule. Ideas for reform in science proposed by Russian scientists display a very similar characteristic. For example, the public value of research versus teaching was rising in all major scientific powers, but in late Imperial Russia this tendency took the form of a demand that scientists should be liberated from teaching

[9] See also "Opisaniya i chertezhi izobreteniy protivogazov i priborov dlya bor'by s otravlyayushchimi veshchestvami, 1915–1917" VIA, f. 507, op. 5, d. 72; and "Svedeniya o yezhednevnom proizvodstve protivogazov, 1917," VIA, f. 504, op. 16, d. 179.

[10] On other nations, see Dewey 1988; Haber 1986; Hardach 1992; Hartcup 1988; MacLeod 1993, 1998; Trebilcock 1993.

obligations altogether and recognized as a separate profession with their own specialized institutes for research. After several twists and turns during the turbulent second decade of the century, this idea materialized in revolutionary Russia and eventually became the single most characteristic feature of the Soviet system of science.

The adage that "the success of science (and technology) is impossible without emancipating the modern scientist from his obligations as a teacher" belongs to Kliment Timiryazev, the famous plant physiologist from Moscow University and a radical democrat by political convictions. Timiryazev came to this conclusion in 1911 in response to two important events of that year, the infamous Kasso affair in Moscow and the founding of the Kaiser Wilhelm Gesellschaft in Berlin. A few months earlier, the governing body of Moscow University, its Academic Council, was caught in a conflict between radical students and the police. By Russian standards, a student meeting on the university campus in memory of the recently deceased Count Lev Tolstoy was viewed as political, and therefore illegal. After all, Tolstoy was not only the country's greatest novelist but also a dissident religious thinker officially excommunicated from the Russian Orthodox Church. The police entry on campus in order to prevent students from meeting was also illegal, as it violated the principle of university self-governance. In protest of this violation, the rector, Aleksandr Manuylov, and two other highest elected officials of the University, Mikhail Menzbir and Pëtr Minakov, resigned from their administrative posts. To reprimand them, the minister of Enlightenment, Duke Kasso, not only accepted their resignations as administrators, but also fired them from their professorial positions. This abuse of power triggered a wave of solidarity resignations among other members of the Academic Council. In total, about a quarter of the faculty – more than 100 professors and privatdocents – resigned in a rather bold act, since only few of them could have reasonable hopes of obtaining positions elsewhere, outside the system of state schools.[11]

Never before – except perhaps in the devastating fire during Napoleon's occupation of 1812 – had Moscow University experienced such a damaging blow, and the public outcry against government "obscurantism" ran high, especially in the Moscow press. Since Timiryazev had already reached retirement age, his personal resignation was largely an act of symbolic protest, but as a public figure, he was one of the most principled and vocal critics of the regime. Other timely news arrived from the foreign press, allowing Timiryazev to discuss the treatment of science in the favorite Russian genre of political discourse, by juxtaposing and contrasting Russia to some mythical, undifferentiated "West." Typical for "us," in his narrative, was the pogrom of Moscow University faculty by Kasso and state bureaucrats, while characteristic for "them" was the opening ceremony of the Kaiser Wilhelm Gesellschaft in Berlin with its projected dozen research institutes. Although one might question the value of the genre of festive speeches as a source of real

[11] See the description of the Kasso affair in P. N. Lebedev to F. A. H. Krüger, February 1911 (Lebedev 1990, 358–359). For a general study of the conflicts at Russian universities in the early twentieth century, see Kassow 1989.

information, Timiryazev extracted from Emil Fischer's opening address the conclusion he wanted: that Germans held science in such high regard as to establish separate institutes for researchers "without teaching obligations" (Timiryazev [1911] 1963).

Timiryazev was not only an influential scientist, but also a true democrat. His unreserved belief in science was matched only by his unreserved belief in democracy and, furthermore, by the insistence that the two had to come hand in hand. To hold such views in the early twentieth century – when Germany led the world in many sciences – was somewhat counterfactual, but Timiryazev was not discouraged by this inconsistency. He was confident not only that science under Anglo-Saxon democracies must be much better off than in imperial Germany, but also that it had surely advanced further in the progressive trend of liberating science from teaching. After all, he had heard something about the Carnegie Institution in Washington and about the "endowment of research" in Britain, and he misinterpreted these examples as proof for his claim (Timiryazev [1911] 1963, 58).

In accordance with the genre rules of writing on "Russia and the West," Timiryazev depicted his country as backward for still having "all its science concentrated in universities," while "the entire civilized world" had recognized the highest value of research itself. The massive resignation of Moscow professors had proved to him that scientists could not be free as long as they remained in their teaching positions as state employees. The Kasso affair destroyed the international pride of Moscow science, Pëtr Lebedev's laboratory in the cellar of the Physics Institute. Lebedev, famous for the experimental discovery of the pressure of light, left the university together with most of his students, thus losing his well-equipped laboratory and with it the possibility of continuing a productive research program. Timiryazev appealed to Moscow merchants to save "their" Lebedev and help create "safe havens for scientific research" in the form of research institutes independent of state universities. He remained fully convinced that his proposal to separate science and university education was following the general trend of more developed countries rather than embarking on an original path of institutional development (Timiryazev [1911] 1963, 58, 65).

Timiryazev's call found a warm reception among many other scientists and publicists, but the idea developed further in two distinctively different forms. Timiryazev and other Moscow authors argued for the establishment of non-governmental facilities for research and looked towards private philanthropy for support. Like Lebedev, many Moscow professors came from the merchant estate themselves or had other personal ties to families of major local merchants and industrialists, who by the early twentieth century had developed a taste for cultural philanthropy (Buryshkin 1991). The initiative of professors who resigned resulted in 1912 in the founding of the (awkwardly named) Moscow Society for Scientific Institute with the purpose of raising private funds and donations for the construction of non-governmental research institutes (Zernov 1912). Four such institutes – in physics, chemistry, biology, and the social sciences – were planned, and two were actually built despite the on-going war. After Lebedev's premature death of heart disease in 1912, his pupil Pëtr Lazarev continued pushing forward the construction of the Physical Institute and eventually became its director, while the Biological Institute came to be directed by Nikolay Kol'tsov. Both institutes opened in 1917, on the eve of the revolution, and later became the nuclei of the much larger Soviet institutions.

In contrast to the Moscow academics, their colleagues in St. Petersburg had much closer relations – personal and otherwise – to the state bureaucracy, and typically looked to the government as a source of patronage. The Imperial Academy of Sciences in St. Petersburg used the occasion of Mikhail Lomonosov's bicentennial in 1911 – marked by the festive official celebrations of the proclaimed founding father of national Russian science – to lobby the establishment of a large Lomonosov Institute for research in three fields: physics, chemistry, and mineralogy. The proposal received His Majesty's approval, but was later postponed due to the Great War and never materialized (Bastrakova 1999; Imperatorskaya 1917, 102–106). The idea of state research institutes, however, did not die. Another major spokesman for Russian science, Vladimir Vernadsky (Vernadskiy) from the Academy of Sciences, modified it according to the new situation during the war and made first steps towards its practical realization, with huge consequences for the post-revolutionary period.

3. The Study of Natural Productive Forces

World War I cultural propaganda centered around the theme of the holy struggle between civilization, culture, and barbarity. Russia's traditional dependence on Europe, particularly Germany, made it harder for Russian authors to use the language of militant cultural nationalism that permeated the writings of French, German, and British war ideologues. Russian educated elites could easily formulate their opposition to the "Teutonic race" in nationalistic, monarchist, religious, or moral terms, but not in terms of cultural superiority. Instead, they pictured Russia's war as a war for cultural and economic independence against the cultural imperialism of Germans. Once the war broke out, Russian writers who had previously decried the country's backwardness in inflated terms started calling its lack of culture only "illusory" and claiming that "the victory over Germany is necessary in the name of [European] culture" (Brenchkevich 1915, 32; Grimm 1915, 14–15; Trubetskoy 1915).

Compared to religious philosophers, scientists in Russia had even fewer reasons to claim nationalistic cultural superiority. Unlike their western colleagues, they typically produced rather moderate, almost internationalist statements, and complained most strongly about the damage done by the war to international exchange and communication in science. The pacifist Timiryazev was on the left side of the political spectrum, and even during the war continued to proclaim science as a universal, international, and rational activity, denouncing all its military applications

(Timiryazev [1915] 1963). Vernadsky, geologist and geochemist, was much closer to the political center and also much younger. He was one of the leaders of the constitutional democrats, the political party of liberal opposition in late Imperial Russia that favored the establishment of a constitutional monarchy and was nicknamed "the party of professors," since its Central Committee consisted mostly of established academics. Vernadsky had also resigned from Moscow University during the Kasso affair of 1911; he was later elected to the Imperial Academy of Sciences and moved to St. Petersburg. As the major wartime public spokesman of science, he represented the Academy rather than universities.[12]

The war had a great impact on Vernadsky's scientific and social views. He felt that the tremendous movement of human masses during mobilization resembled the power of geological forces, which prompted his investigation of global, geological effects of human activities, the long line of inquiry that established his later reputation as one of the founding fathers of ecological thought. In historical terms, Vernadsky predicted that the on-going war – like the decades of European wars after 1789 – would mark the transition to a new historical era, in particular with regard to the role and the importance of science "because of its real applications to the interests of defense, despite moral reservations" (Vernadsky [1916a] 1922, 54). Like most Russian scientists, Vernadsky lamented the interruption of scientific contacts between belligerent nations, mistakenly believing that scientific research in other European countries continued on its prewar scale:

> As we know, we are continuing our scientific work with the same speed. Our work is developing and improving now, and it also had not been interrupted or slowed down in the years of our other national disturbances – either during the war with Japan or in the years of the revolution [of 1905]. (Vernadsky [1915a] 1922, 135)

Whether Vernadsky understood it or not, his statement reflected the fact that Russian science was much less integrated into the total war effort than science in Britain, Germany, or France. He acknowledged, at least, that it was ill-prepared for the new tasks, and he expected major changes to happen in the immediate postwar period: "[Although] the development of science will not stop the war, . . . regardless of the outcome of the war, both winners and losers will have to direct their thought towards further development of scientific applications to the military and navy affairs" (Vernadsky [1915a] 1922, 131–132).

According to Vernadsky, the most important task facing postwar Russian science would not be the competition with other nations in pure science, but the study of Russia's own natural resources and productive forces:

> Russian society has suddenly realized its economic dependence on Germany, which is intolerable for a healthy country and for an alive strong nation . . . . [This dependence]

[12] See the biographies of Vernadsky (Mochalov 1985; Bailes 1990).

> has transcended the limits of necessary, unavoidable and profitable exchange of products of nature, labor, and thought between two neighboring nations. It has developed into an exploitation of one country by the other . . . . One of the consequences – and also one of the causes – of Russia's economic dependence on Germany is the extraordinary insufficiency of our knowledge about the natural productive forces with which Nature and History has granted Russia. (Vernadsky [1915b] 1922, 5)

By his count, only 31 out of 61 economically useful chemical elements were mined and produced in Russia. Even aluminum had to be imported, since deposits of bauxite had not yet been explored. Vernadsky believed that practically any useful mineral could be found in the country's enormous territory and referred to this work as "necessary for national security," since Russia had to catch up with other nations in this regard (Vernadsky [1916a] 1922, 65). Following his proposal, in February 1915 the Imperial Academy of Sciences abandoned its century-long tradition of concentrating on pure science and established a Commission for the Study of Natural Productive Forces of Russia (KEPS) (Kol'tsov 1999, 14–15). The task of KEPS, according to Vernadsky, encompassed the study of all kinds of national resources and called for collaboration and mobilization of geologists, mineralogists, zoologists, botanists, chemists, physicists, and even social scientists, which would follow the example of the war-time "mobilization of various engineers who work on the basis of exact sciences, physicians, bacteriologists, and . . . chemists." Vernadsky was aware that these plans could be realized fully only after the end of the war, but he insisted that preparations had to start right away. He did not worry too much about wartime expenditures on the project that would bear fruit only in the long run, because "one can establish all the necessary research institutes at the expense of just one super-dreadnought" (Vernadsky [1916a] 1922, 54–5, 68).

With regard to these mobilization plans, science and scientific manpower began to be considered among the country's most important resources. The Academy in Petrograd together with the editorial board of the Moscow scientific periodical *Priroda* established a joint commission to prepare the first national census of academic populations and institutions. In early 1917, questionnaires were distributed to all known scholarly institutions in Russia, and the answers were collected by the year's end from both capitals – Petrograd and Moscow – and from the majority of provinces. Due to revolutionary unrest, the results of the survey could not be published as planned in early 1918. With financial help from the Bolshevik's Commissariat of Enlightenment, the two volumes were published a couple years later, containing unprecedented but by that time already somewhat outdated demographic information on science and scientists in Petrograd and Moscow almost exactly on the eve of the November 1917 Bolshevik coup (Nauka 1920–1922).

Vernadsky did not need to wait for the results of the census to declare in 1915 that the war had revealed that the existing scientific infrastructure was totally insufficient for the proposed grand project and that cardinal changes were needed there as badly as they were needed in Russia's political system:

> After the war of 1914–1915 we will have to make known and accountable the natural productive forces of our country, i.e. first of all to find means for broad scientific investigations of Russia's nature and for the establishment of a network of well equipped research laboratories, museums and institutions . . . . This is no less necessary than the need for an improvement in the conditions of our civil and political life, which is so acutely perceived by the entire country. (Vernadsky [1915a] 1922, 140)

Itself an assembly of research laboratories by statute, the Academy of Sciences in terms of its financing was one of the institutions of the royal court and thus naturally expected state patronage. The support it already had, however, was certainly inadequate for the proposed goal of KEPS, but Vernadsky insisted that the work had to start immediately, without waiting for the war's end. As the first step, he proposed the preparation of a series of publications with detailed summaries of the available knowledge on Russia's energy, minerals, ores, plants, animals, and chemical factories. He specifically listed some minerals that were in great demand and had to be searched for without delay. With an initial modest contribution from the Academy's budget, KEPS commissioned a number of scientists to write such reviews, which were published as the series *Materials for the Study of the Natural Productive Forces of Russia*.

Reviewing the results of the first year, Vernadsky formulated an ambitious plan of further reform directed toward "a new organization of scientific work" on the national level. His scheme consisted of (1) the national congress of scientists for the discussion of the study of productive forces, (2) coordination of scientific work for the sake of planned research, and (3) creating new research institutions: museums, laboratories and institutes. Vernadsky specifically elaborated on the latter point, arguing that the entire national network of specialized research institutes of applied, theoretical, and mixed nature was needed as a matter of state priority and that KEPS should draft plans for them. He was convinced that "the higher schools alone cannot satisfy the growing needs of scientific research," and therefore of the "impossibility and the disadvantage of the permanent linking of all scientific research work to the institutions of higher education" (Vernadsky [1916b] 1922, 29).

In his 1916 report to KEPS, Vernadsky mentioned plans for an institute on clay and aluminum, and for an experimental station on Kara-Bugaz Bay on the Caspian Sea (a deposit of raw salts). In the following year, KEPS drafted proposals for a half-dozen more research institutes and laboratories of applied aims (Platinum, Physico-Chemical Analysis, Hydrology, Alloys and Metallography, Petroleum), while learned societies proposed several more institutes (Metallurgy, Pharmaceuticals, Chemical Reagents, Coal) (Bastrakova 1973, 46–49). The idea of separate research institutes thus appeared again, this time in the form of a much broader and comprehensive network and within the context of the important practical task facing the nation.

Many years later, some Soviet historians referred to Vernadsky's proposal of 1916 as a prophetic anticipation of the Soviet system of planned research with the Academy as its highest administrative body. Although some aspirations apparently had been present all along, the Academy would not be able to achieve this until some twenty years later, in the mature Stalinist society (Vucinich 1984). For the immediate turbulent decade of wars and revolutions, however, the significance of the Academy and KEPS would be less in administering, than in part encouraging, in part coordinating, but most of all reflecting the general trend. Similar processes were developing largely independently at various locations throughout the Empire, as formerly "pure" academics were turning toward work that was of economic and military importance, establishing nuclei of new research institutions, and preparing blueprints and proposals for expanded postwar activity along these lines. It was specifically these wartime proposals and activities that – after 1917 – provided the foundation for the emerging special relationship between science and the revolutionary government.

4. Revolution and the War's Legacy

Timiryazev's pacifism contributed to his rapprochement with the Bolsheviks, the only political party in Russia that opposed the imperialist war on principle. Ailing health did not permit the patriarch of Russian science to participate personally in the organizational reform of scientific institutions, but his public position helped forge the pact between research-oriented academics and the Soviet regime. Timiryazev became the first famous scientist to express open support for the Bolshevik-led government when it was still struggling to consolidate its power. Grateful Bolsheviks helped Timiryazev with the publication of his volume of collected public essays and speeches, *Science and Democracy*, which came out in 1920 and received a particularly warm welcome from Lenin (Timiryazev [1920] 1963). The 1911 article on the liberation of science from teaching was reprinted in the volume and thus appeared to have received the highest political approval.

Yet even without waiting for Lenin's indirect endorsement, scientists and Soviet officials quickly agreed on the idea that a research institute was the best and the most progressive way of organizing science. To Nikolay Gorbunov – then probably the most influential patron of science in Bolshevik circles – the concept looked so genuinely revolutionary that he managed to insert a phrase about linking research to industrial production and establishing the "entire network of new scientific applied institutes, laboratories, experimental stations, and testing facilities" into the new Communist Party Program adopted at the 1919 Party Congress (Bastrakova, Ostrovityanov, et al. 1968, 91; Gorbunov 1986, 14–15). A young chemical engineering graduate from Petrograd Technological Institute, Gorbunov was one of the few important Bolsheviks who possessed technical expertise and thus played a crucial role in designing early Soviet policies regarding science and technology.[13]

[13] Gorbunov's influence depended not so much on his relatively low formal rank in the party hierarchy than on his post as the secretary of the Soviet government, which provided him direct access to all important decision makers. For more on his role in the organization of Soviet science, see Gorbunov 1986.

Sergey Ol'denburg, the permanent secretary of the Russian Academy of Sciences, summarized the mutual consensus a few years later in the following formula: "while the eighteenth century was, for science, the century of academies, the nineteenth century became the century of universities, and the twentieth century is starting to become the century of research institutes" (Ol'denburg 1927, 89).

The Bolsheviks bought into the idea even more readily, as it helped them to win over scientists as collaborators and simultaneously to sort out their ambivalent relationship with professors. While being enthusiastically pro-science at the most extreme – for both ideological and pragmatic reasons – the Bolsheviks often perceived as "counter-revolutionary" the predominant species among the real-life carriers of scientific knowledge, the college professor. Many university councils, indeed, openly protested the ousting of the Provisional government by the Soviets in November 1917, and, even more importantly, faculty representatives effectively rejected the proposal of a radically egalitarian, democratic reform of higher education drafted by the Commissariat of Enlightenment in spring 1918 (Smirnova 1979). Ever since, the Soviet officials had treated defenders of academic autonomy with suspicion and hostility, but they generally gave a much warmer welcome to the very same individuals when they appeared in the role of scientists or experts rather than faculty members. Even the leader of liberal university opposition, biologist Mikhail Novikov, collaborated very successfully with the industrial commissariat as the head of the Moscow commission of scientific experts, while at the same time, in his other role as the rector of Moscow University, he organized strikes of university professors and struggled bitterly against the Commissariat of Enlightenment (Novikov 1930). Novikov ended up being exiled from the country in 1922 together with some 160 representatives of the academic opposition, but many more scholars found that the newly organized research institutes offered them a much more comfortable and freer shelter than the politically and administratively embattled universities. The resulting gradual flow of scientists from teaching to research positions made it easier for the Bolsheviks to start replacing old bourgeois professors with politically and ideologically more loyal teachers of students.

For scientists and scientific experts for the government, the criterion of political loyalty was generally much lower than for university teachers. General Ipatieff was a monarchist and did not welcome even the February revolution, thinking that "a constitutional monarchy would have served Russia's needs best." He had no belief in the Bolsheviks' utopian goals, although he gave them credit for one thing, that "having gained control of the nation, they made the only sensible move possible in concluding peace immediately" (Ipatieff 1946, 246, 263). When the Bolsheviks usurped political power in the capital, Ipatieff persuaded his subordinates at the military Chemical Committee that "army men had no right to stop their work in war time" and that "the government in power should be obeyed." He took a similar line at the meeting of the Physico-Mathematical division of the Academy of Sciences:

> Control of the state belong[s] to the group capable of setting up a strong government. . . . In the period [of general dissatisfaction] the intelligentsia . . . should not try to oppose the new government. Our personal feelings toward the Bolshevik regime were ours alone and no one could force us to express them. The autocracy of the Tsarist regime had dissatisfied many of us; yet we had continued to do our duty. (Ipatieff 1946, 259–260)

With such an understanding of Russian national interests and of his own duty, Ipatieff did not hesitate to start an immediate active collaboration with the new regime in his professional role as a military scientist. The Bolsheviks for their part entrusted the monarchist with high-level posts within the Soviet government. In May 1920 Ipatieff was appointed to direct the former Central Scientific-Technical Laboratory of the War Ministry, soon to be renamed the State Scientific-Technical Institute (GONTI). Subsequently, as a member of the governing collegium of the economic commissariat VSNKh, he was effectively in charge of the nation's chemical industry and research (Ipatieff 1946, 285–330).

As a liberal, and also a deputy Minister of Enlightenment in the last version of the Provisional Government, Vernadsky was much less inclined to cooperate with the Soviet regime. Together with several other officials of the deposed government, he signed an appeal to the Russian public protesting the Bolshevik coup. After the Bolsheviks ordered the arrest of signatories and the closing of the newspapers that published the document, Vernadsky decided to escape temporarily from Petrograd, take a leave from the Academy of Sciences and depart for his family home in a Ukrainian province (Vernadsky 1994, 223–224). The permanent secretary of the Academy and the former minister in the Provisional government, Ol'denburg, remained in the capital and played a key role in the negotiations with the Commissariat of Enlightenment. Initially, the Academy felt no less hostile towards the Bolsheviks than the universities and learned societies, but it also had a much stronger tradition of political obedience and privileged proximity to autocratic power. After debating the matter, the Academy leadership decided to refrain from issuing an open protest against the Bolshevik coup, and a few months later concluded an agreement with the Soviet government.[14]

The Bolsheviks wanted the Academy to embark on research related to the "rational development of industry and the rational distribution of the country's economic forces" and were less interested in its traditional emphasis on "pure theoretical sciences." The ground for the compromise was found in the activities of KEPS, the Commission for the Study of Natural Productive Forces. In return for material support and respect for its self-administration, the Academy expressed its agreement to work on "topics originating from the needs of state-building, while acting as the organizational center of the national research effort" (Bastrakova 1973, 127, 141). On

[14] See the correspondence between the Academy and Narkompros in February-April 1918 in Bastrakova, Ostrovityanov, et al. 1968, 103–128.

12 April 1918 the Soviet government, Sovnarkom, approved funding for KEPS, which allowed the commission to develop activities on a much broader scale. The first two institutes proposed by KEPS – on physico-chemical analysis, and on platinum and precious metals – started working in the summer of 1918, followed by institutes on hydrology, ceramics, radium, and soil (Kol'tsov 1999, 80–85).[15] In Vernadsky's absence, the work of KEPS was coordinated by his former student and the commission's secretary Aleksandr Fersman. The Academy quickly promoted the 35-year-old geologist to full membership, and in May 1920 Fersman departed for the Kola Peninsula at the head of the complex scientific expedition to study the Russian North (Fersman 1968). The expedition found rich deposits of phosphate minerals in the Khibin Mountains along with other ores and resources and it marked the beginning of the Soviet scientific and industrial cultivation of the unexplored north-eastern territories, which would later become one of the chief economic priorities for the Stalinist regime and its GULAG system of forced labor.[16]

Competition between Soviet commissariats stimulated the mushrooming of new research institutes. The Commissariat of Enlightenment, Narkompros, managed to monopolize the country's educational system but could not prevent other emerging Soviet bureaucracies – in particular economic (VSNKh), medical (Narkomzdrav), agricultural (Narkomzem), army and navy (Narkomvoenmor) and communications (Narkompochtel') – from developing their own research and development empires. The large majority of the new institutes originated from proposals or activities that went back to World War I or slightly preceded it. What used to be the experimental factory of the Russian Physico-Chemical society's War Chemical Committee became the Institute of Applied Chemistry under VSNKh. The industrial commissariat also nationalized the private institute *Lithogaea* as the Institute of Applied Mineralogy and reorganized the research laboratory on automobiles as the Automotive Institute (NAMI). By 1920 VSNKh controlled 16 research institutes, including the Central Aero-Hydrodynamic Institute (TsAGI) that worked on the design of airplanes, the institutes on metrology, food, fuel, fertilizers, and pure chemicals (Bastrakova 1973, 178–186; Bastrakova, Ostrovityanov, et al. 1968, 283–311). The nationalization of banks deprived the Moscow Society for Scientific Institute of its financial assets, but its recently completed physical and biological institutes became, respectively, the Institute of Physics and Biophysics and the Institute of Experimental Biology under Narkomzdrav (Bastrakova 1973, 200). Two other formerly private institutions, Lesgaft Biological Laboratory (renamed the Institute for Natural Sciences) and Bekhterev's

[15] For the documents on the institutes of physico-chemical analysis, platinum, clay, and hydrology, see Bastrakova, Ostrovityanov, et al. 1968, 129–142, 150–165. A general report on KEPS activities throughout the Civil War years was published in Lindener 1922. KEPS's publishing activity rose despite the catastrophic economic situation from 85 printed pages in 1915, to 732 in 1916, 416 in 1917, 893 in 1918, 2038 in 1919, and 2264 in 1920 (Blok 1921).

[16] On other expeditions organized by KEPS during the Civil War – the salt expeditions to Solikamsk and Kara-Bugaz, the bauxite expedition, the West-Siberian expedition, and the exploration of the Kursk magnetic anomaly, see Bastrakova, Ostrovityanov et al. 1968, 177–193; and Man'kovskiy 1960.

Institute for Brain Research, found a new patron in Narkompros (Bastrakova, Ostrovityanov, et al. 1968, 251–258). Narkompochtel' undertook the commission to organize research on radio and in 1919 established the Central Radio Laboratory in Nizhniy Novgorod. By different estimates, 40 to 70 research institutes were created in the country by the end of the Civil War (Bastrakova 1973, 221–231, 162; Bastrakova, Ostrovityanov, et al. 1968, 8).

The Bolshevik government was the most important, but by no means the only political authority that supported scientific research in the Civil War-torn territory of the former Empire. The revolutionary chaos and armed conflict led to the decentralization of the political sphere and created more de-facto room for local initiatives by scientists and activist groups. Dozens of local proposals of new universities and institutes of higher learning that had been either turned down or red-taped by the rigid Tsarist bureaucracy received approval more easily – even if sometimes only on paper and with the primary hope of attaining better legitimacy – from the unstable Civil War administrations and rival regimes. Ten universities were opened in the country during the preceding 150 years of the monarchy, and no less than 24 new ones appeared in just the four years of the revolution and the Civil War. The new schools were founded by a variety of administrations, both Red and White ones, in the approximate proportion of two to one (Chanbarisov 1988, 39–55). Not all of them survived the turbulent years, but the majority did and changed forever the national scene of higher learning.

Vernadsky's Civil War odyssey is particularly illustrative, since he managed to work under nearly all possible regimes, pursuing with a reasonable degree of success the same line of reform in science. At first, he organized KEPS and drafted proposals for a number of research institutes at the Imperial Academy of Sciences in Petrograd; he then continued the same activity under the Provisional Government. After he moved to Ukraine in early 1918, Vernadsky founded a local KEPS in his native Poltava province and later played a key role in the organization of the Ukrainian Academy of Sciences (with its own KEPS and research institutes) in Kiev, the capital of the newly proclaimed independent nation. The vulnerable Academy managed to survive all changes of political and military power in Kiev: from the German-backed regime through local nationalists, Soviet Red Army and White occupations, to the Ukrainian Soviet Republic. All, except White Russians who were the most hostile to Ukrainian independence, granted the Academy some kind of political patronage. During the White occupation in 1919, Vernadsky traveled south to meet with generals and plead on the Academy's behalf and, as a result of contracting typhus and changed military fortunes, got stuck in the White Crimea. There he was elected rector of the recently founded Tauride University and organized – of course – one more KEPS, this time to study the natural productive forces on the Crimean peninsula. Once the Red armies overran the last White stronghold in late 1920 and many academics – including George, his son – sailed off from the Crimea towards permanent emigration, Vernadsky returned to Petrograd to work under the Bolsheviks at the Russian Academy. In late 1921 he transformed the former radium commission of his original KEPS into a full-scale Radium Institute with two departments, physical and chemical. Shortly thereafter, Vernadsky delegated the institute directorship to his deputy, radiochemist Vitaliy Khlopin, accepted a visiting professorship in Paris and went abroad with the official permission of the Soviet government.[17]

In the course of the Civil War, Bolshevik commissars fully accepted as "socialist" the idea of specialized research institutes separated from higher education, which had been developed by Russian academics shortly before the revolution. It corresponded well with their own bureaucratic and political interests and eventually became the dominant institutional form of Soviet science. Most of the newly established research units would be called "institutes," and many older ones – laboratories, bureaus, experimental factories and stations – were renamed and reorganized into institutes. Bolsheviks especially welcomed research proposals that combined utilitarian goals with modernist, revolutionary overtones, and thus were particularly receptive to the novel undertakings that had started during World War I and reflected its needs. The chaotic and utopian mood of the revolutionary period allowed many proposals to win easy approval without long and careful consideration by the authorities. A number of the institutes did not survive the social difficulties of the Civil War and the financial shortages of the post-war transition to the New Economic Policy or survived only on paper. Several dozen of them, however, proved viable throughout all the turmoil and determined the future direction of the Soviet scientific effort. The period of prolonged war, revolution, and international isolation lasted overall from 1914 till 1921. Once it was over, Russian scientists could once again exchange information with foreign colleagues, occasionally travel to Europe, and compare their accomplishments with what had been achieved elsewhere. But by that time Soviet Russia had already established the foundation of its distinctive system of research and development. One of the best illustrations, and also one of the most important examples of this general process, is the story of optical glass.

5. From Optical Glass to the Optical Institute

In the 1930s, Sergey Vavilov, physicist, historian of science, and coordinator of Soviet optical industry, lamented that after a great start in the late eighteenth century and the important inventions by Euler, Lomonosov, and Aepinus, research on applied optics and optical instrumentation was practically neglected in Russia for almost a hundred years (Vavilov [1935] 1956, 147). Serious work had to start again from scratch in the early twentieth century. The young military engineer Yakov Perepëlkin, a graduate of the Artillery Academy, arrived in 1899 at the Obukhov Steel Works in St. Petersburg

[17] On Vernadsky's travels, see his Civil War diary (Vernadskiy 1994); for documents on the first years of the Ukrainian Academy of Sciences, see Istoriya 1993; for academic life in the Crimea, see Vernadskiy 1921; in the Russian North, see Zhdanko 1922.

with a commission from the Navy Ministry to organize the production of modern optical sights for naval and coastal artillery. By 1905 – during the war with Japan – he established at the factory a special optical workshop that manufactured artillery sights of several types from imported optical parts and from locally designed mechanical parts. Perepëlkin invited two military scientists as consultants: the applied mathematician and naval engineer Aleksey Krylov and the physicist Aleksandr Gershun. In 1906 Gershun quit his teaching job at the Artillery Officers' Class in Kronstadt to become the workshop's full-time employee and later director. By 1912, the optical workshop manufactured a wider assortment of military optical devices, including binoculars and range-finders, and employed some 150 workers, which still did not satisfy the army's needs even during the period of peace (Chenakal 1947, 161–162).

The workshop's employment expanded dramatically during the Great War and reached almost 700 in 1917. Meanwhile, shortly before his death in 1915, Gershun managed to start another, private optical factory under the newly organized Russian Optico-Mechanical Joint-Stock Company. Both were mobilized to work on military needs, together with a few smaller private workshops and with two sequestered Riga-based subsidiaries of the German optical firms Zeiss and Hertz. The main bottleneck during wartime, however, was the shortage of optical glass. In the pre-war decades, Germany alone possessed the advanced know-how and had practically monopolized the world production of high-quality optical glass. Both Russia and her allies had depended on the imports of such glass from Germany and had to undertake urgent measures during the war to develop their own production. On behalf of the Chief Artillery Administration, Lieutenant-General A. L. Korol'kov inspected all existing optical facilities and estimated the total amount of optical glass available at the start of the war to be somewhat below one ton. Korol'kov then turned for help to the administration of the Imperial Porcelain and Glass Factory in Petrograd.[18]

The situation became critical in the fall of 1915: optical factories were about to stop production due to the shortage of glass, while attempts to import glass from England and France had not been very successful since the Allies experienced shortages themselves. Meanwhile, the first series of experiments on the production of optical glass at the Porcelain Factory had convinced the military of the necessity to conduct extended research and to "bring into the effort scientific and technical experts."[19] The factory's chief engineer, Nikolay Kachalov, appointed a young chemist Il'ya Grebenshchikov as the head of the optical glass workshop and invited as consultants several academic scientists, including the university physicist Dmitriy

[18] "Perepiska . . . o zakupkakh, dostavke i proizvodstve opticheskogo stekla i priborov . . . , 1914–1916," VIA, f. 504, op. 10, d. 8, pp. 2–39. On German optical industry and the wartime problem of the production of the optical glass and military optical equipment in other belligerent countries, see Feffer 1994; Hagen 1996; MacLeod and MacLeod 1975; MacAdam 1964.

[19] "Perepiska . . . o zakupkakh, dostavke i proizvodstve opticheskogo stekla i priborov . . . , 1914–1916," VIA, f. 504, op. 10, d. 8, pp. 81–83, 99, 300, 305–306. See alo "Perepiska . . . o zakazakh opticheskogo stekla inostrannym firmam, 1915–1917" VIA, f. 504, op. 10, d. 64.

Rozhdestvenskiy (Chenakal 1947, 163; Grebenshchikov and Rozhdestvenskiy [1918a] 1993).

The son of a historian and high-level official at the Ministry of Enlightenment, Rozhdestvenskiy graduated from St. Petersburg University in 1900 and was subsequently employed there as assistant at the Physical Institute. Together with his friends Paul Ehrenfest (Pol' Erenfest) and Abram Ioffe, Rozhdestvenskiy founded the circle of young physicists and challenged the authority of senior St. Petersburg professors who – unlike Lebedev in Moscow – were oriented towards teaching rather than advanced research. The young Turks' career advancement was hampered by a number of bureaucratic problems. Ehrenfest – an Austrian Jew married to a Russian and without any official religious affiliation – could not find a regular position in Russia and eventually left the country in 1912 to succeed Hendrik Antoon Lorentz at the University of Leiden. Rozhdestvenskiy and Ioffe became professors only in 1915, the former at the University and the latter at the Polytechnical Institute. By that time, Rozhdestvenskiy was already one of the world's leading experts on spectroscopy and the author of an ingenious method for studying anomalous dispersion that provided important results for the emerging quantum theory of the atom.[20]

Almost simultaneously with his appointment, Rozhdestvenskiy became director of the University's Physical Institute and was also invited to be a consultant for the production of optical glass at the Imperial Porcelain Factory. He readily acquiesced to the idea of working on war-related needs alongside scientific research and started attending a vocational school to learn the professional technician's skill of glass cutting and polishing (Gulo and Osinovskiy 1980, 67). Meanwhile, Grebenshchikov traveled to Britain to learn the Allies' know-how. With his and other consultants' guidance, the optical glass workshop delivered its first quantities of glass to instrument factories in May 1916. By the time of the revolution one year later, it had produced approximately three tons of glass of an expanding assortment but with still very unstable and barely acceptable quality. In order to solve this problem, Rozhdestvenskiy set up a special research group at the University's Physical Institute and also added a calculating bureau to design optical instruments. In their ambitious plans, Russian scientists envisioned an entire research-cum-production complex with an advanced laboratory, a specialized optical glass factory, and a factory for manufacturing optical devices (Grebenshchikov and Rozhdestvenskiy [1918b] 1993, 22; Frish and Stozharov 1976, 28; Gulo and Osinovskiy 1980, 67–68).

The February revolution and the end of the monarchy initially inspired huge public enthusiasm, but the mood quickly turned sour as the new Provisional Government was unable to control persistent conflicts and revolutionary chaos spread rapidly across the country. Due to unrest among workers and to the new

[20] On Rozhdestvenskiy's biography and his studies of anomalous dispersion, see Frish, Stozharov 1976; Gulo, Osinovskiy 1980; and the essay by S. E. Frish in the volume of selected papers by Rozhdestvenskiy (1951). On Ehrenfest (Ehrenfest) see the biographies by Frenkel' (1977) and Klein (1970). On Ioffe, see the books by Josephson (1991) and Sominskiy (1964).

administration's change of priorities, by the end of 1917 the production of optical glass at the Porcelain Factory was disorganized, and cadres of qualified workers fled. Rozhdestvenskiy saved the research part of the enterprise by transferring it to Vernadsky's KEPS in May 1918, where it was reconstituted as the Department of Optical Technology. One of the first if not the very first among academic institutions, KEPS started receiving subsidies from the new Bolshevik government in spring 1918 and submitted proposals for several research institutes. Among the plans for possible further actions discussed within KEPS during the summer of 1918 was the idea of an Optical Institute (Gulo and Osinovskiy 1980, 69).

Meanwhile, Rozhdestvenskiy received another offer that came from Petrograd medical circles. Since 1913 Mikhail Nemenov and several other activists among medical doctors were trying to organize the Russian Society of Roentgenologists and Radiologists. They finally succeeded in 1916 and in December of that year convened the society's first all-Russian congress in Moscow to discuss the uses of X-rays in war medicine (Troitskaya 1920). According to Nemenov's recollections, in 1913 he submitted the first proposal to turn his X-ray laboratory at the Women's Medical Institute into a radiological institute, but with the start of the war the project was shelved. In March 1918 Nemenov turned with the same idea to Anatoliy Lunacharsky (Lunacharskiy), the Commissar of Enlightenment in the new Bolshevik government, and, with some astonishment, saw his proposal approved within a few days. Acting in a fast revolutionary way, Nemenov appropriated or usurped for the new institute several buildings of the former Lyceum, a school for nobles, and medical equipment from the community war clinic where he served as the chief physician (Nemenov 1920; 1928, 2–6). In September, Lunacharsky approved the organization of the institute's second department, physico-technical, under the directorship of the physicist Ioffe from Petrograd Polytechnical Institute. The department's task was to study physical phenomena associated with X-rays and to test X-ray tubes and equipment for the medico-biological department. Because of the tensions with other physicians and especially with the administration, the State Roentgenological and Radiological Institute (GRRI) separated completely from the Women's Medical Institute in October 1918, thus also achieving the separation between teaching and research. The institute's statute adopted in the same month envisioned the creation of two more departments: on optics – with Rozhdestvenskiy in mind – and on radium (Bastrakova, Ostrovityanov, et. al. 1968, 232–237; Nemenov 1928, 6–8; Sominskiy 1964, 195–198).[21]

[21] The Optical department within GRRI never materialized, while the radium department remained largely inactive due to the early death of its director, L. S. Kolovrat-Chervinskiy, until it was absorbed into Vernadsky's Radium Institute in 1922. In late 1921 GRRI split into two separate institutes, medico-biological and physico-technical. The latter, directed by Ioffe, subsequently became so much more prosperous and famous under the name of Leningrad Physico-Technical Institute, that historical narratives often overlook its early status as a department within the more complex, multidisciplinary GRRI. The exceptions are two detailed studies of the Physico-Technical Institute and of the activities of its director A. F. Ioffe (Sominskiy 1964 and Josephson 1991).

Either of these ways would have probably worked for Rozhdestvenskiy, but he definitely preferred the third opportunity that arose almost simultaneously. With the start of the Civil War in summer 1918, the all-but-abandoned military production became important once again to satisfy the needs of the newly created Red Army. On 18 October the Chief Artillery Administration under the new red leadership requested credit from the Bolshevik government for the restoration of the optical industry.[22] On 15 November Rozhdestvenskiy received a letter from Nikolay Gorbunov, in which the secretary of the Soviet government and a chief official at the economic commissariat (VSNKh) inquired about the possibilities of resuming the production of binoculars for the Red Army. Rozhdestvenskiy, whose political views were socialist, replied without delay with an ambitious proposal for the revival of the entire optical industry through scientific leadership. Exactly one month later, upon receiving encouragement from Bolshevik officials, he invited twenty colleagues and researchers to the founding meeting of the State Optical Institute (Gulo and Osinovskiy 1980, 70).

6. From the Optical Institute to an Optical Industry: Modernization, Soviet Style

At the meeting convened by Rozhdestvenskiy on 15 December 1918, a document was adopted and sent to the Commissariat of Enlightenment proposing a novel kind of academic institution, "in which science and technology would be inseparably linked together." The proposal argued that it was impossible for an individual university laboratory to cope with the increased complexity and expenditures of modern theoretical and experimental optics. A larger separate institution was thus needed to conduct planned research in the field in a centralized and coordinated way. At the same time, the new technological tasks of the optical industry and glass production required increased involvement of science on an everyday basis. The proposed State Optical Institute promised to answer both these demands by fusing advanced scientific research in fundamental optics with the design and industrial production of sophisticated optical technology (Rozhdestvenskiy [1918] 1993; Frish and Stozharov 1976, 67). Accordingly, the Institute consisted of two departments – science and technology – with tasks defined as:

> I. Scientific Tasks:
> 1. Research on optics in the visible, infrared and ultraviolet regions, in particular with regard to the questions of the constitution of the atom . . .

[22] "Perepiska s . . . Petrogradskim opticheskim zavodom o snabzhenii etogo predpriyatiya opticheskim steklom, 1916–1919," VIA, f. 504, op. 10, d. 89, p. 425–426.

> 2. The creation and maintenance of central experimental devices for optical research in the Republic, devices that exceed the capacities of individual university laboratories; . . .
> II. Technical Tasks:
> 1. Research on optical instruments and devices . . . in the Laboratory of Geometrical Optics;
> 2. An Optical Workshop for the production of precision devices . . .;
> 3. A Calculating Bureau for the design of large optical systems (also serving the needs of the State Obukhov and Pig Iron Plants), of national importance;
> 4. Assisting the development of optical technology in Russia; . . . (Polozheniye [1918] 1993, 52)

The emphasis on collectivism, centralism, and large experimental devices that could not be managed by individual university laboratories and institutes justified the dimensions of the proposed enterprise. Designed with the goal of solving a complex technological problem, the institute ignored traditional disciplinary boundaries in science. It was de facto multidisciplinary in character and employed engineers together with scientists of diverse backgrounds. Thus, while the State Roentgenological and Radiological Institute simultaneously pursued research and new X-ray technology in medicine, physics, and geology, the Optical Institute combined physics, chemistry, mathematics and engineering.

A separate appendix demanded further that the production of optical glass should be taken from the Porcelain Factory and transformed into a separate optical glass factory, to be run by a "scientific collegiate body," comprised mostly of representatives of the Optical Institute. An additional factory for the manufacturing of optical devices also had to be established and subordinated to scientists in a similar way. Scientists thus claimed responsibility not only for research and design of technology, but for controlling regular industrial production as well:

> The scientific element has to play the leading role in the factory, just as it played de facto before [during the World War]. Seriously, the problem of optical glass is more a scientific rather than a technical problem, and the factory would thus appropriately belong to the Commissariat of Enlightenment. Rather than just consulting, scientific cadres should have a decisive word in all main issues. Currently, consultants cannot get their recommendations fulfilled . . . and the entire production halted. It is clear that the factory administration has to be put under the real and powerful control of a scientific *collegium*, which clearly understands the national importance of the production of optical glass and, together with the factory administration, determines technical plans and their fulfillment. (Gulo and Osinovskiy 1980, 76–77)

On 26 April 1919, the Commissar of Enlightenment, Anatoliy Lunacharsky, signed the official decree establishing the State Optical Institute. The laconic text approved the main principles proposed by scientists – the institute with two departments and with the optical glass factory subordinated to it – but did not specify the exact method of how the factory had to be administered (Gulo and Osinovskiy 1980, 81–82). Without waiting for official approval, Rozhdestvenskiy and his colleagues started the Institute de facto in just a fortnight after the initial founding meeting. The Institute's first list of staff included 35 specialists (Polozheniye [1918] 1993, 51). In January 1919 they hired the first dozen additional "technicians" selected from among the student body of the University.[23] While continuing to take classes at the physico-mathematical department, students received their first practical assignments at the State Optical Institute along with food rations, a matter of life and death in a freezing and starving Petrograd. The institute itself was initially housed in several rooms of the university's Physical Institute, until Rozhdestvenskiy managed to get hold of an adjacent empty building of a nationalized candy factory. With thick walls, deep cellars and spacious rooms, the building was found perfectly suitable for conducting experiments in optics. In February 1919 the newly organized institute hosted the first Congress of Russian physicists, which established the national learned society, the Russian Association of Physicists (Kononkov and Osinovskiy 1968).[24]

While creating unprecedented opportunities for radical reforms and institutional novelties, the revolution and the civil war also destroyed most of the material conditions for normal work, especially in Petrograd and other big cities overwhelmed by cold, starvation, and anarchy in the streets. The general economic disorganization and the flight of skilled workers to their native villages brought the optical glass production to a halt in 1919.[25] By year's end Rozhdestvenskiy could report only a theoretical piece of work, though one with revolutionary aspirations. Typed invitations to his presentation at the Optical Institute in December 1919 assured Petrograd physicists of an incredible luxury: a heated lecture hall. The audience had to arrive on foot, since the city trams were not running, and listened to the speaker, who was feeling "very weak, but with a mind exceptionally clear, thanks to malnutrition" (Gulo and Osinovskiy 1980, 88). In his presentation, Rozhdestvenskiy challenged the Sommerfeld theory of 1916, the improvement of the 1913 Bohr atomic model and one of the last pieces of scientific news to reach Russia before the total break of communications with colleagues in Europe. He generalized the elliptic orbital model for alkali metals, succeeded in classifying their spectra, and, most importantly, concluded that atoms have an inner magnetic field which – rather than relativistic effects – caused the doublet separation of spectral lines (Rozhdestvenskiy

[23] Several of them later became famous scientists: Vladimir Fock, Aleksandr Terenin, Lev Shubnikov, Sergey Frish and Yevgeniy Gross (Gorokhovskiy 1968, 12). Like many other scholars, Rozhdestvenskiy initially hoped to retain his teaching position alongside his new research job at the institute. In 1919 he pushed forward a major reform of the physics curriculum at Petrograd University. By the mid–1920s, however, he had to quit his university professorship due to disagreements with Narkompros over teaching methods, and concentrated on research at the Optical Institute (Frish 1992, 129–130). The episode is symptomatic of the growing administrative separation between advanced teaching and advanced research in the Soviet system.
[24] The subsequent activities of the Russian Association of Physicists have been studied in Josephson 1991.
[25] The Petrograd population fell from 2.42 million in 1917 to 720 thousand in 1920, partly from disease, cold, and hunger, but mostly from people fleeing to the countryside closer to supplies of food.

1920). Having no other means of relating the news to foreign colleagues, Petrograd physicists broadcast a radio message addressed to Lorentz and Ehrenfest in Leiden:

> Professor Rozhdestvenskiy succeeded in proving that spectral series of all elements correspond to Sommerfeld's ellipses. The normal structure of lithium is established. Doublets in series are caused by the magnetic field of the inner shells. Krutkov is working on the anomalous Zeeman effect and on the normal effect in strong fields. Bursian is studying the electric influence of inner shells. We have no literature since the beginning of 1917. The collegium of the Optical Institute requests information on what has been done on related problems outside Russia. Please address the radio message to Rozhdestvenskiy, University, Petrograd. The help is kindly requested from the Amsterdam Academy in shipping scientific literature. Greetings from the Petrograd physicists. (Levshin 1986, 155–6)

Soviet newspapers published inflated reports of a "world-class scientific discovery," the proof of the divisibility of atoms and of the Soviet government's generous support of science. A different ideology – the obsession with world domination – showed up in the misrepresentation of the radio message in British media: the journal *Nation* commented that if the information on a Russian scientist's mastery of atomic energy were true, the owner of the secret would be positioned to rule the entire planet. Upon receiving a report from Rozhdestvenskiy, Narkompros approved funding for the special Atomic Commission to work on the mathematical theory of the atom, which marked the beginning of Soviet theoretical physics. For almost two years, the Commission provided twenty physicists and mathematicians – including Vladimir Fock (Fok) and Alexander Friedmann (Aleksandr Fridman)– with Red Army military rations, which undoubtedly saved several lives. During this time, Friedmann produced the first really great achievement in Soviet physics: two papers on non-stationary solutions in Einstein's general relativity, the cornerstone of all modern theories of the expanding Universe (Friedmann 1922, 1924; Gulo and Osinovskiy 1980, 92–96; Tropp et al. 1993).

As the Civil War drew to a close, the Academy of Sciences sent a report to the Soviet government on the critical situation in Russian science and the urgent need to restore its contacts with the West.[26] Several senior scientists – including Nemenov, Ioffe, Krylov and Rozhdestvenskiy – were sent abroad in late 1920 and early 1921 with the primary goal of purchasing scientific literature and instruments. Rozhdestvenskiy received the astronomical sum of 200,000 hard currency rubles (an estimated $80,000) to equip the Optical Institute. Inflation in Germany allowed him to use this money very effectively. Stuffed with the most up-to-date instruments, the institute counted 86 staff members in 1922 (more than half of them scientists) and embarked on intensive research in several directions: spectroscopy and quantum theory, optical

[26] "Zapiska rukovodstva Akademii nauk v SNK ob okazaniy material'noy i organizatsionnoy pomoshchi nauchnym uchrezhdeniyam," 22 November 1920, published in Levshin 1986, 174–178.

glass technology, geometrical optics and the design of optical devices, physical and later also electron optics, photography, photometry and photochemistry.[27]

The same team that tried to make optical glass during the war – the engineer Kachalov, the chemist Grebenshchikov, and the physicist Rozhdestvenskiy – now took on the task of organizing its full-scale production. After a serious fight with the administration of the Porcelain Factory and with industry officials who insisted on continuing imports, Rozhdestvenskiy pushed forward the decision to separate the optical glass workshop as an independent factory under Kachalov's directorship. Appropriate funding came only at the end of 1923, when the factory changed its affiliation from Narkompros to the much more powerful industrial commissariat VSNKh. Production resumed in February 1924 with monthly output rising to six tons by the summer. The problems with quality and assortment lasted well into 1926, when Optical Institute scientists developed the original know-how, which allowed the Soviet Union to stop importing optical glass after 1927 (Grebenshchikov 1933; Rozhdestvenskiy 1932; Gulo and Osinovskiy 1980, 105–130).

The initial success formed the basis for the Optical Institute's subsequent leading role in the creation of the entire Soviet optical industry. The institute's staff grew in the process to 240 in 1931 and 600 in 1936 (Gorokhovskiy 1968, 13, 21), while the Soviet Union developed into an independent producer and later exporter of optical technology. The work done at the institute ranged from Fock's fundamental theories of the atom (the Fock-Hartree method) and Terenin's discovery of the superfine structure of atomic spectra to the design of the entire spectrum of optical devices – lamps, cameras, microscopes, telescopes, sights, etc. – for both civilian and military use. The balance between different aspects of research – fundamental and applied, military and civilian, classified and open – was changing with time and often created problems, especially in the early 1930s when Rozhdestvenskiy resigned from the directorship over disagreements with industrial officials.[28] The basic principle of combining science with technology, and physics with chemistry and engineering, however, remained valid for the entire Soviet period.

The experience of the Optical and other early institutes set the paradigmatic example for the general Soviet style of industrial modernization, which was driven primarily by science rather than by market mechanisms. The mainstream method of creating new technology in the Soviet Union – since the 1920s and at least until the end of the Stalin period – consisted in setting up a special research institute in association with an experimental factory or workshop, whereby the institute and its researchers enjoyed a substantial degree of authority over industrial production, rather than the reverse. As the key element of the Soviet modernization effort, such

[27] On Rozhdestvenskiy's foreign trip and purchases, see Gulo and Osinovskiy 1980, 98–104.

[28] The complicated story of the Optical Institute transcends the scope of this investigation and largely remains to be written. For the in-house history of the institute and its fifty years of research in fundamental, applied, and technological directions, see Gorokhovskiy 1968. For revealing informal recollections by one of its leading physicists, see Frish 1992.

institutes – often nicknamed "the general staff" of the corresponding industry – shared responsibility for many of its successes and failures.

Conclusions

As the Civil War came to an end, the academic community reviewed on the pages of its new mouthpiece, *Science and Its Workers*, what had happened to science in various parts of the country, in the center as well as in Siberia and in the Crimea. In the journal's editorial manifesto, the KEPS secretary Fersman formulated the two main tasks facing Russian scientists. The first one – international – was to restore contacts with foreign colleagues, to resume the exchange of ideas and information and to "fight with all forces of persuasion against the chauvinism of some countries that resist contacts between former enemies." The second one – domestic – was to foster new collective forms of the organization of research and to build up the "state network of scientific research institutions," especially applied ones. In an exalted style that reflected the characteristic revolutionary utopianism, Fersman anticipated radical changes in institutions as well as in the content of science:

> In these years, when the foundations of a new scientific worldview are laid, when old schemes are broken, when the great new achievements that apparently contradict common sense are growing upon the ruins of what was thought to be the unshakable truth; in these years when the bold flight of creativity of the scientist can only be compared to the fantasy of the poet; in these years new forms of scientific work are forged, and scientific thought imperatively seeks new paths, along which it would victoriously proceed towards great new accomplishments. (Fersman 1921, 3)

Vernadsky echoed this message in a private letter from Paris to his émigré friend and former political comrade-in-arms Ivan Petrunkevich:

> It seems to me that here [in the West] they do not recognize the huge cultural task that has been accomplished, accomplished in the face of sufferings, humiliations, destruction. . . . Of course, in a police state . . . freedom is relative and it is necessary to defend it continually. A lot has been created in Moscow and Petersburg, de facto a lot, although little by comparison with the plans of 1915–1917. And curiously enough, a lot has been created in the provinces. (Vernadsky to I. I. Petrunkevich, 10 March 1923, quoted in Bailes 1989, 268, 291)

New scientific forms, indeed, were forged out of the innovative World War I proposals modified by revolutionary visions. Although their development was anything but orderly, certain important tendencies prevailed. Most of the new institutes were organized by professors and some remained affiliated with universities and colleges, yet an increasingly dominant trend consisted of their institutional separation from higher education. Their favorite form – a state-sponsored research institution directed simultaneously towards advanced research and a utilitarian service – was closer to the proposal by Vernadsky of 1916 than to that by Timiryazev of 1911. The popular organizational principles emphasized centralism, planning, collectivism, and a quantum leap towards largesse in all quantitative measures – personnel, instruments, networks – over the previous generation of research laboratories. The magnificent practical, even if not always realistically achievable, goal reflected the typical revolutionary combination of utopianism and utilitarianism. The hope was often founded upon a radically novel theory or technology with revolutionary symbolism, such as radio, aviation, automobile, genetics, X-rays, or radioactivity. The appropriate research and development enterprises usually had to be multidisciplinary in character. Their tasks often included production – manufacturing X-ray tubes, making optical glass, designing aircraft, or improving the sorting of grain – and many of the institutes had experimental factories or production units closely associated with or administratively subordinated to research, rather than the reverse.

Loren Graham has described the birth of the characteristically Soviet system of research institutes as "the combination of revolutionary innovation and international borrowing" (Graham 1975). The current study shows that the above formula needs to be modified. It was, indeed, a revolutionary innovation, but one that started already before the revolution itself and did not originate from a particular political or ideological agenda of a revolutionary party. Instead, it came from scholars who responded to the crisis of World War I and to the general revolutionary situation in the country, which contributed to the radicalism of their proposals. After the revolution, Bolsheviks accepted, endorsed, and internalized many essential elements of the proposed reform of science not only because they were almost as strongly pro-science as the researchers themselves, but also – and not in a small sense – because they, too, operated in the same situation of the war and revolutionary crisis. The values and interests of scientists and of the Soviet government overlapped, in particular, in the idea of a research institute, which helped materialize the proposed reform and gave it its specific spin.

A kind of international borrowing also existed, but a rather ironic one. Exact borrowing between different cultures is hardly possible even under the most favorable conditions. In the story presented above, Russia's international isolation during the war appears to have been a much more effective factor than the desire of its academics to imitate the "West." Russian scientists sensed and shared the general international trends of the period, such as the growing recognition of science as a profession, the tighter links between research and technology, especially military technology, and the resulting increase of governments' interest in science and science policy. They presented their proposals – sincerely as well as rhetorically – as following and catching up with other major scientific nations. The real information they had about the developments in other countries, however, was not only severely limited, but also reinterpreted by them in a rather idiosyncratic way. As a result, Russian scientists designed what was, in fact, a novel system of research and development.

During the same period, scientists in other European countries, including Britain, advanced similar proposals for "centrally planned and government-funded" science, public science policy, the opening of new institutions for linking advanced research to industrial and military needs, and an increased political role for scientists (Turner 1980; Wang 1995; Hull 1999). In France, Marie Curie lobbied for the organization of a laboratory-factory, supervised by scientists, funded by the government, and responsible for running the national radium industry (Boudia and Roqué 1997, 253; Roqué, forthcoming). Even in the United States, less affected by the war, George Hale tried to reform the National Academy, create centralized national laboratories, and connect pure science with military preparations (Tobey 1971, ch. 2). Some of these initiatives failed, others succeeded partly, or temporarily, for the period of war, and retreated afterwards. In Civil-War Russia, assisted by the revolutionary desire for radical change, scientists managed to realize similar proposals in a much more comprehensive, abrupt way, and to preserve the result during the ensuing period of peace under the notion of "Soviet (or socialist) model of research."[29] International influence of this institutional model started already in the 1920s, when it was borrowed by the nationalist Guomindang regime in the Republic of China (Greene 1997).

Elsewhere, most notably in the United States, comparable changes occurred later, typically as a result of another World War, and survived afterwards in the form of national laboratories and other institutions, under the unofficial name "big science" (the label "socialist" could not be used during the Cold War for obvious reasons). Despite the difference in names, the two phenomena are homologous and apparently are parts of the same social process. They share most of the essential features, such as gigantomania, state support, the cult of science in society, (con)fusion between science and engineering, multidisciplinary research, collective or team work, complex bureaucracy and militarization. Historians have already referred to Soviet science as the ultimate example of "big science," although without explicitly pointing out that it chronologically preceded the better known cases.[30] The mentality and propaganda of the Cold War period paid more attention to ideological contrasts and oppositions between the rival systems, while usually inventing different names for or turning a blind eye towards similarities. Looking back now at the experience of the past century from a less partisan perspective, on the contrary, reveals ever more of its common trends.

[29] The episode is not an isolated phenomenon, but part of a more general trend, in which the Russian revolution served as a springboard for jumping from backwardness to utopia, pioneering and testing (sometimes prematurely, or ahead of better prepared nations) many of the essential social and economic innovations of the twentieth century (Carr 1947; Hoffmann and Holquist, forthcoming).

[30] See, for example, Graham 1992. The basic historical account of the big science, however, overlooks the existence of an earlier Soviet version (Galison and Hevly 1992).

Acknowledgments

I thank Dietrich Beyrau, Olga Elina, Paul Forman, Michael Gordin, J. L. Heilbron, Peter Holquist, John Krige, Jessica Wang, Peter Westwick, and two anonymous referees for comments and criticism.

References

Aleksandrov, D. A. 1996. "Pochemu sovetskiye uchënyye perestali pechatat'sya za rubezhom: stanovleniye samodostatochnosti i izolirovannosti otechestvennoy nauki, 1914–1940." *Voprosy istorii yestestvoznaniya i tekhniki* No.3:3–24.

Bailes, Kendall E. 1989. "Natural Scientists and the Soviet System." In *Party, State, and Society in the Russian Civil War. Explorations in Social History,* edited by Diane P. Koenker, William G. Rosenberg, Ronald Grigor Suny, 267–295. Bloomington: Indiana University Press.

Bailes, Kendall E. 1990. *Science and Russian culture in an age of revolutions: V. I. Vernadsky and his scientific school, 1863–1945*. Bloomington: Indiana University Press.

Barsukov, E. Z. 1938. *Russkaya artilleriya v mirovuyu voynu*. Moscow.

Bastrakova, M. S. 1973. *Stanovleniye sovetskoy sistemy organizatsii nauki (1917–1922).* Moscow: Nauka.

Bastrakova, M. S. 1999. "Akademiya nauk i sozdaniye issledovatel'skikh institutov (dve zapiski V.I.Vernadskogo)." *Voprosy istorii yestestvoznaniya i tekhniki* No.1:157–167.

Bastrakova, M. S., K.V. Ostrovityanov, et al., eds. 1968. *Organizatsiya nauki v pervyye gody Sovetskoy vlasti (1917–1925). Sbornik dokumentov.* Leningrad: Akademiya nauk SSSR.

Blok, G. 1921. "Izdatel'skaya deyatel'nost' K.E.P.S." *Nauka i yeyë rabotniki* No.1:25–27.

Boudia, Soraya and Xavier Roqué, eds. 1997. *Science, Medicine, and Industry: The Curie and Joliot-Curie Laboratories*. Special issue, *History and Technology* 13:241–343.

Brenchkevich, M. V. 1915. *Velikaya yevropeyskaya voyna, yeyë istoricheskiye osnovy i smysl*. Moscow-Petrograd: A. S. Panafidina.

Brooks, Nathan M. 1997. "Chemistry in War, Revolution, and Upheaval: Russia and the Soviet Union, 1900–1929." *Centaurus* 39:349–367.

Bukshpan, Ya.M. 1929. *Voyenno-khozyaystvennaya politika. Formy i organy regulirovaniya narodnogo khozyaystva za vremya mirovoy voyny 1914–1918 gg*. Moscow-Leningrad: Gosizdat; RANION.

Buryshkin, P. A. 1991. *Moskva kupecheskaya*. Moscow: Sovremennik.

Carr, Edward Hallett. 1947. *The Soviet Impact on the Western World*. New York: Macmillan.

Chanbarisov, Sh. Kh. 1988. *Formirovaniye sovetskoy universitetskoy sistemy.* Moscow: Vysshaya Shkola.

Chenakal, V. L. 1947. "Optika v dorevolyutsionnoy Rossii." *Trudy instituta istorii yestestvoznaniya i tekhniki*. 1:145–167.

Chichibabin, A. E. 1914. "O medikamentakh." *Russkiye Vedomosti* 188:6; 189:5.

Chichibabin, A. E. 1915. "Khimicheskaya promyshlennost' i nauka." *Russkiye Vedomosti* 4:6.

Dewey, Peter E. 1988. "The New Warfare and Economic Mobilization." In *Britain and the First World War,* ed. by John Turner, 70–84. London: Unwin Hyman.

Dmitriyev, I. S. 1996. " 'Osobaya missiya' Mendeleyeva: fakty i argumenty." *Voprosy istorii yestestvoznaniya i tekhniki* No.3:126–141.

Edgerton, D. E. H. 1996. "British scientific intellectuals and the relations of science, technology, and war." In *National Military Establishments and the Advancement of Science and Technology,* edited by Paul Forman and José M. Sánches-Ron, 1–35. Dordrecht: Kluwer.

Feffer, Stuart M. 1994. "Microscopes to Munitions: Ernst Abbe, Carl Zeiss, and the Transformation of Technical Optics, 1850–1914." Ph.D. diss., University of California, Berkeley.

Fersman, A. E. 1921. "Puti nauchnogo tvorchestva." *Nauka i yeyë rabotniki* No.1:3–7.

Fersman, A. E. 1968. *Nash apatit*. Moscow: Nauka.

Frenkel', V. Ya. 1977. *Paul' Erenfest*, 2d ed. Moscow: Atomizdat.

Friedmann (Fridman), A. 1922. "Über die Krümmung des Raumes." *Zeitschrift für Physik* 10:377–387.

Friedmann, A. 1924. "Über die Möglichkeit einer Welt mit konstanter negativer Krümmung des Raumes." *Zeitschrift für Physik* 21:326–333.

Frish, S. E. 1992. *Skvoz' prizmu vremeni: Vospominaniya*. Moscow: Izdatel'stvo politicheskoy literatury.

Frish, S. E. and A. I. Stozharov, eds. 1976. *Vospominaniya ob akademike D.S. Rozhdestvenskom*. Leningrad: Nauka.

Galison, Peter and Bruce Hevly, eds. 1992. *Big Science: The Growth of Large-Scale Research*. Stanford: Stanford University Press.

Gatrell, Peter. 1986. *The Tsarist Economy, 1850–1917*. New York: St. Martin's Press.

Gatrell, Peter. 1994. *Government, Industry and Rearmament in Russia, 1900–1914: The Last Argument of Tsarism*. Cambridge: Cambridge University Press.

Gorbunov, N. P. 1986. *Vospominaniya. Stat'i. Dokumenty.* Moscow: Nauka.

Gordin, Michael Dan. 2001. "The Ordered Society and Its Enemies: D. I. Mendeleev and the Russian Empire, 1861–1905." Ph. D. diss., Harvard University.

Gorokhovskiy, Yu. N., ed. 1968. *50 let Gosudarstvennogo opticheskogo instituta im. S.I. Vavilova (1918–1968)*. Leningrad: Mashinostroyeniye.

Graham, Loren R. 1975. "The Formation of Soviet Research Institutes: A Combination of Revolutionary Innovation and International Borrowing." *Social Studies of Science* 5:303–329.

Graham, Loren R. 1992. "Big Science in the Last Years of the Big Soviet Union." In *Science after '40*, edited by Arnold Thackray. *Osiris* 7:49–71.

Grebenshchikov, I. V. and D. S. Rozhdestvenskiy. [1918a] 1993. "Zapiska konsul'tantov Gosudarstvennykh Farforovogo i Steklyannogo Zavodov po voprosu o vydelenii Zavoda Opticheskogo Stekla." *Trudy Gosudarstvennogo Opticheskogo Instituta im. S. I. Vavilova* (Transactions of the S. I. Vavilov State Optical Institute), Vol. 83, Issue 217, 1993, Supplement, 17–18.

Grebenshchikov, I. V. and D. S. Rozhdestvenskiy. [1918b] 1993. "O znachenii zavoda opticheskogo stekla dlya Rossii." *Trudy Gosudarstvennogo Opticheskogo Instituta im. S. I. Vavilova* (Transactions of the S. I. Vavilov State Optical Institute), Vol. 83, Issue 217, (1993), Supplement, 19–24.

Grebenshchikov, I. V. 1933. "Opticheskoye steklo i razvitiye yego proizvodstva v SSSR." *Trudy noyabr'skoy yubileynoy sessii AN SSSR 1932* g. Leningrad. 448-455.

Greene, J. Megan. 1997. "Ideology and Expertise: The Guomindang and Talent in China's Nanjing Decade, 1927–1937." Ph.D. diss., Washington University, St. Louis.

Grimm, E. D. 1915. "Bor'ba narodov." In *Voprosy mirovoy voyny. Sbornik statey*, edited by M. I. Tugan-Baranovskiy, 1–19. Petrograd: Pravo.

Grinevetskiy, V. I. 1922. *Poslevoyennyye perspektivy Russkoy promyshlennosti*. Kharkov.

Gulo, D. D. and A. N. Osinovskiy. 1980. *Dmitriy Sergeyevich Rozhdestvenskiy.* Moscow: Nauka.

Haber, L. F. 1986. *The Poisonous Cloud: Chemical Warfare in the First World War.* Oxford: Clarendon Press.

Hagen, Antje. 1996. "Export versus direct investment in the German optical industry: Carl Zeiss, Jena and Glaswerk Schott & Gen. in the UK, from their beginnings to 1933." *Business History* 38:1–20.

Hardach, Gerd. 1992. "Industrial Mobilisation in 1914–1918: Production, Planning and Ideology." In *The French Home Front, 1914–1918*, edited by Patrick Friedenson, 57–88. Providence: Berg.

Hartcup, Guy. 1988. *The War of Invention: Scientific Developments, 1914–1918*. London: Brassey's Defense Publishers.

Hoffmann, David L. and Peter Holquist. Forthcoming. *Cultivating the Masses: The Modern Social State in Russia, 1914–1941*. Ithaca: Cornell University Press.

Holquist, Peter. 1997. "Information is the Alpha and Omega of Our Work: Bolshevik Surveillance in its Pan-European Context." *Journal of Modern History* 69:415–450.

Hull, Andrew. 1999. "War of Words: the Public Science of the British Scientific Community and the Origins of the Department of Scientific and Industrial Research, 1914–16." *British Journal for the History of Science* 32:461–481.

Imperatorskaya Akademiya Nauk. 1917. *Materialy dlya istorii akademicheskikh uchrezhdeniy za 1889–1914 gg.* Chast' 1. Petrograd: Imperatorskaya Akademiya nauk.

Ipatieff (Ipat'ev), V. N. 1946. *The Life of a Chemist: Memoirs of Vladimir N. Ipatieff.* Stanford: Stanford University Press.

Istoriya. 1993. *Istoriya Akademii Nauk Ukraini, 1918–1923. Dokumenty i Materialy.* Kyiv: Naukova Dumka.

Josephson, Paul. 1991. *Physics and Politics in Revolutionary Russia.* Berkeley: University of California Press.

Kassow, Samuel D. 1989. *Students, Professors, and the State in Tsarist Russia.* Berkeley: University of California Press.

Klein, Martin J. 1970. *Paul Ehrenfest.* Amsterdam: North Holland.

Kol'tsov. A. V. 1999. *Sozdaniye i deyatel'nost' Komissii po izucheniyu yestestvennykh proizvoditel'nykh sil Rossii, 1915–1930 gg.* St. Petersburg: Nauka.

Kononkov, A. F. and A. N. Osinovskiy. 1968. "Sozdaniye sovetskoy optiki i deyatel'nost' D. S. Rozhdestvenskogo." In *Ocherki po istorii sovetskoy nauki i kul'tury,* 113–135. Moscow: Moscow University Press.

Kovalevskiy, V. I., ed. 1900. *Rossiya v kontse XIX veka.* St. Petersburg: Brokgauz-Efron

Lebedev, P. N. 1990. *Nauchnaya perepiska P. N. Lebedeva*, edited by E. I. Pogrebysskaya. Moscow: Nauka.

Levshin, B. V., ed. 1986. *Dokumenty po istorii Akademii nauk SSSR, 1917–1925.* Leningrad: Nauka.

Lindener, B. A. 1922. *Raboty Rossiyskoy Akademii nauk v oblasti issledovaniya prirodnykh bogatstv Rossii; obzor deyatel'nosti KEPS za 1915–1921 gg.* Petrograd: Rossiyskaya Akademiya nauk; KEPS.

Lomonosovskiy 1901. *Lomonosovskiy Sbornik. Materialy dlya istorii razvitiya khimii v Rossii.* Moscow: Mamontov.

MacAdam, David L. 1964. *Early Rochester History of the Optical Society. An Inquiring Sketch* (unpublished manuscript). Niels Bohr Library, American Institute of Physics.

MacLeod, Kay and Roy MacLeod. 1975. "War and Economic Development: Government and the Optical Industry in Britain, 1914–1918." In *War and Economic Development: Essays in Honour of David Joslin*, edited by Jay M. Winter, 165–204. Cambridge: Cambridge University Press.

MacLeod, Roy. 1993. "The Chemists Go to War: the Mobilization of Civilian Chemists and the British War Effort, 1914–1918." *Annals of Science* 50:455–481.

MacLeod, Roy. 1998. "Chemistry for King and Kayser: Revisiting Chemical Enterprise and the European War." In *Determinants in the Evolution of the European Chemical Industry, 1900–1939*, edited by Anthony S. Travis et al., 25–49. Dordrecht: Kluwer.

Mal'kov, V. L., ed. 1998. *Pervaya mirovaya voyna: prolog XX veka.* Moscow: Nauka.

Manikovskiy, A. A. 1920. *Boyevoye snabzheniye russkoy armii v voynu 1914–1918 gg.* Chast' 1. Moscow: Voyenno-istoricheskaya komissiya.

Man'kovskiy, G. N. 1960. "K istorii izucheniya Kurskoy magnitnoy anomalii." *Trudy instituta istorii yestestvoznaniya i tekhniki* 33:3–16.

Markovnikov, V. V. [1879] 1955. "Sovremennaya khimiya i russkaya khimicheskaya promyshlennost." In V. V. Markovnikov, *Izbrannyye trudy,* 637–676. Moscow: Akademiya nauk SSSR.

Mochalov, I. I. 1982. *Vladimir Ivanovich Vernadskiy, 1863–1945.* Moscow: Nauka.

Nametkin, S. S. 1954. "Nikolay Dmitriyevich Zelinskiy. Biografiya i ocherk nauchnoy deyatel'nosti." In N. D. Zelinskiy, *Sobraniye trudov,*. T. 1:7–66. Moscow: Akademiya nauk SSSR.

Nauka. 1920–22. *Nauka v Rossii. Spravochnyy Yezhegodnik (dannyye k 1 yanvarya 1918 g.* Vyp. 1. Petrograd (Petrograd 1920); Vyp. 2 Moskva (Petrograd 1922).

Nemenov, M. I. 1920. "Mediko-Biologicheskiy Otdel Gosudarstvennogo Rentgenologicheskogo i Radiologicheskogo Instituta i deyatel'nost' ego v 1919 godu." *Vestnik Rentgenologii* 1:153–174.

Nemenov, M. I. 1928. "K istorii osnovaniya Gosudarstvennogo rentgenologicheskogo i radiologicheskogo instituta. Po lichnym vospominaniyam." In *Gosudarstvennyy rentgenologicheskiy, radiologicheskiy i rakovyy institut*, 1–25. Leningrad.

Novikov, M. M. 1930. "Moskovskiy universitet v pervyi period bol'shevistskogo rezhima." In *Moskovskiy Universitet, 1755–1930*, 156–192. Paris.

Novorusskiy, M. V. 1915. "Voyna i novyye otrasli russkoy promyshlennosti." In *Voprosy mirovoy voyny. Sbornik statey,* edited by M. I. Tugan-Baranovskiy, 466–483. Petrograd: Pravo.

Ol'denburg, S. F. 1927. "Vpechatleniya o nauchnoy zhizni v Germanii, Frantsii i Anglii." *Nauchnyy rabotnik* No.2:88–101.

Pestre, Dominique and John Krige. 1992. "Some Thoughts on the Early History of CERN." In Galison and Hevly 1992, 78–99.

Pisarev, Yu.A. and V. L. Mal'kov, eds. 1994. *Pervaya mirovaya voyna: Diskussionnye problemy istorii*. Moscow: Nauka.

Polozheniye. [1918] 1993. "Polozheniye o gosudarstvennom Opticheskom institute." In *Trudy Gosudarstvennogo Opticheskogo Instituta im. S. I. Vavilova* (Transactions of the S. I. Vavilov State Optical Institute), 1993 Supplement 83(217):49–52.

Roqué, Xavier. Forthcoming. "Marie Curie's Vision of the Institut du Radium." In *Radioactivity: Science and Culture*, edited by Christine Blondel.

Rozhdestvenskiy, D. S. [1918] 1993. "[Zapiska] v Komissariat Narodnogo prosveshcheniya." In *Trudy Gosudarstvennogo Opticheskogo Instituta im. S. I. Vavilova* (Transactions of the S. I. Vavilov State Optical Institute), 1993 Supplement 83(217):11–14.

Rozhdestvenskiy, D. S. 1920. "Spektral'nyy analiz i stroyeniye atoma." *Trudy Gosudarstvennogo Opticheskogo Instituta.* T. 1, Vyp. 6.

Rozhdestvenskiy, D. S. 1932. "Zapiska ob opticheskom stekle." *Trudy Gosudarstvennogo Opticheskogo Instituta.* T. 8. Vyp. 84.

Rozhdestvenskiy, D. S. 1951. *Raboty po anomal'noy dispersii v parakh metallov.* Leningrad: Akademiya nauk SSSR.

Smirnov, N. N., ed. 1999. *Rossiya i pervaya mirovaya voyna: Materialy mezhdunarodnogo nauchnogo kollokviuma.* St. Petersburg.

Smirnova, T. M. 1979. "Istoriya razrabotki i provedeniya v zhizn' pervogo sovetskogo ustava vysshey shkoly." In *Gosudarstvennoye rukovodstvo vysshey shkoloy v dorevoliutsionnoy Rossii i v SSSR*, edited by N. P. Yeroshkin, 6–38. Moscow: Moskovskiy gosudarstvennyy arkhivnyy institut.

Solov'ëv, Yu. I. 1985. *Istoriya khimii v Rossii. Nauchnye tsentry i osnovnyye napravleniya issledovaniy.* Moscow: Nauka.

Sominskiy, M. S. 1964. *Abram Fedorovich Ioffe.* Moscow-Leningrad: Nauka.

Stone, Norman. 1975. *The Eastern Front, 1914–1917.* New York: Charles Scribner's Sons.

Strumilin, S. 1935. "Khimicheskaya promyshlennost' SSSR." *Problemy ekonomiki* No.2:118–145.

Timiryazev, K. A. [1911] 1963. "Novyye potrebnosti nauki XX veka i ikh udovletvoreniye na zapade i u nas." In Timiryazev [1920] 1963, 56–66.

Timiryazev, K. A. [1915] 1963. "Nauka v sovremennoy zhizni." In Timiryazev [1920] 1963, 342–357.

Timiryazev, K. A. [1920] 1963. *Nauka i demokratiya. Sbornik statey 1904–1919 gg.* Moscow: Izdatel'stvo sotsial'no-ekonomicheskoy literatury.

Tobey, Ronald C. 1971. *The American Ideology of National Science, 1919–1930.* Pittsburgh: University of Pittsburgh Press.

Trebilcock, Clive. 1993. "Science, Technology and the Armaments Industry in the UK and Europe, with special reference to the period 1880–1914." *Journal of European Economic History* 22:565–580.

Troitskaya, T. M. 1920. "K istorii Obshchestva Rossiyskikh Rentgenologov i Radiologov (nyne Rossiyskoy Assotsiatsii Rentgenologov i Radiologov)." *Vestnik Rentgenologii i Radiologii*, 1(1–2):147–150.

Tropp, E. A., V. Ya. Frenkel', and A. D. Chernin. 1993. *Alexander A. Friedmann: The Man Who Made the Universe Expand.* Cambridge: Cambridge University Press.

Trubetskoy, E. N., Prince. 1915. *Voyna i mirovaya zadacha Rossii.* Moscow: Sytin.

Turner, Frank M. 1980. "Public Science in Britain, 1880–1919." *Isis* 71:589–608.

Vavilov, S. I. [1935] 1956. "Fizicheskaya optika Leonarda Eylera." In S. I. Vavilov, *Sobraniye sochineniy,* 3:138–147. Moscow: Akademiya nauk SSSR.

Vernadskiy (Vernadsky), V. I. [1915a] 1922. "Voyna i progress nauki." In Vernadskiy 1922, 129–140.

Vernadskiy, V. I. [1915b] 1922. "Ob izuchenii yestestvennykh proizvoditel'nykh sil Rossii (Dolozheno v zasedanii Fiziko-Matematicheskogo otdeleniya 8 aprelya 1915 g.)." In Vernadskiy 1922, 1:5–25.

Vernadskiy, V. I. [1916a] 1922. "Ob ispol'zovanii khimicheskikh elementov v Rossii." In Vernadskiy 1922, 52–69.

Vernadskiy, V. I. [1916b] 1922. "O gosudarstvennoy seti issledovatel'skikh institutov." In Vernadskiy 1922, 1:25–31.

Vernadskiy, V. I. 1921. "O nauchnoy rabote v Krymu." *Nauka i yeyë rabotniki* No.4:3–12.

Vernadskiy, V. I. 1922. *Ocherki i rechi*. Vol 1. Petrograd: Nauchnoye khimiko-tekhnicheskoye izdatel'stvo NTO VSNKh RSFSR.

Vernadskiy, V. I. 1994. *Dnevniki 1917–1921.* Kiev: Naukova Dumka.

Vucinich, Alexander. 1984. *Empire of Knowledge: The Academy of Sciences of the USSR, 1917–1970.* Berkeley: University of California Press.

Wang, Zuoyue. 1995. "The First World War, Academic Science, and the "Two Cultures": Educational Reforms at the University of Cambridge." *Minerva* 33:107–127.

Yevteyeva, P. M. 1958. "A. E. Chichibabin." *Trudy instituta istorii yestestvoznaniya i tekhniki* 18:296–356.

Zelinskiy, N. D. and V. S. Sadikov. 1918. *Ugol' kak protivogaz*. Petrograd: Khimicheskiy Komitet GAU.

Zelinskiy, N. D. and V. S. Sadikov. [1941] 1960. "Ugol' kak sredstvo bor'by s udushayushchimi i yadovitymi gazami. Eksperimental'noye issledovaniye 1915–1916 gg." In: Zelinskiy, N.D. *Sobraniye trudov.* T. 4: 59–145. Moscow: Akademiya nauk SSSR.

Zernov, M. S. 1912. *Obshchestvo Moskovskogo nauchnogo instituta*. Moscow.

Zhdanko, M. 1922. "O rabote mestnykh sil na severe Rossii." *Priroda* No.3–5:85–88.