Nineteenth Century Physiology in the Making:

Introducing West European Experimentalism to the Russian Context

by

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A thesis submitted in conformity with the requirements

for the degree of Doctor of Philosophy

Institute for the History and Philosophy of Science and Technology

University of Toronto

0-612-74672-0

Abstract

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Ph D Dissertation

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2002

The dissertation is a study of the rise of laboratory science in nineteenth-century Russia. It explores the cross-national scientific connections, which emerged anew after the Crimean war, in the context of the 1860s reforms in Russia and of the development of 'scientific medicine' in Germany.

The thesis focuses on the signal role played by the military in the development of the first in Russia teaching-research laboratories at the St. Petersburg Medico-Surgical Academy. It explores how experimental and teaching practice and its methodology and instrumentation was disseminated from Germany to Russia, and how the innovative techniques and the improved apparatus introduced by I. M. Sechenov and I. F. Cyon into physiological research and teaching contributed to the growth of physiology into a modern scientific discipline. It also discusses the difficulties associated with doing laboratory sciences in Russia by foreground of Sechenov's professional moves, and allows us to picture contrasts in the attitudes and potentialities of War Ministry and Ministry of Education for the introduction of the laboratory.

Sechenov's blood gases and salt solution research and the reception of his methodology are placed within the context of the debate on the solution theory between D. I. Mendeleev and Wilhelm Ostwald's school in Germany.

Thus the thesis outlines the changes Russian scientific culture underwent during the "golden age" of its development in the second half of the nineteenth century wrought by the state, industrial, and military interests.

Acknowledgements

I am greatly indebted to Pauline M. H. Mazumdar, my thesis supervisor, for unfailing encouragement and insightful comments on each stage of my work, and for careful reading of my manuscript, often in more than one version. The countless fascinating conversations we had during these years helped to get me started on the historical path, and contributed to my present work in so many diverse ways that it is impossible to relate them here.

I am deeply thankful to Susan G. Solomon for endless reassurance, when I most needed it, for many stimulating and interesting discussions on the cross-national scientific relations, and for the comments on the entire manuscript of the thesis, which have always been extremely positive and helpful. I am grateful to Trevor H. Levere for valuable discussions on the history of chemistry, especially of the role of instrumentation and experiments, and suggestions at a later stage of my work on the thesis, and for his generous support during my stay at the Institute.

I acknowledge with gratitude the funding of my thesis research for three years (1999-2002) by the Hannah Institute for the History of Medicine. I am also thankful to the University of Toronto's Joint Initiative in German and European Studies for a Dissertation Fellowship (2001), and to the School of Graduate Studies for Travel Grants (1999, 2001). I am grateful to the faculty of the IHPST for providing me with supportive intellectual environment during my five years there, and to the administrative staff and my fellow-students for providing me with friendly assistance as I adjusted to a new city, a new language, and new academic environment.

I would like to thank the many archivists and librarians, who facilitated my research, and to many scholars, who have been generous with assistance, in Russia, Germany and Austria. My special thanks to V. O. Samoilov, Professor of Physiology at the Military-Medical Academy, and to Iu. P. Golikov, Director of the Museum of Experimental Medicine, in St. Petersburg, and to N. A. Grigoryan, the historian of medicine, in Moscow for much interesting information and helpful advice. I am particularly grateful to Professor Ingrid Kästner and the staff of the Karl-Sudhoff-Institut für Geschichte der Medizin for their most friendly welcome and an invaluable guide to the University of Leipzig. I am thankful to professor Thomas Schlanke, Director of the Charité Medizinhistorisches Museum and Dr. Petra Lennig, who granted me generous use of valuable materials of the museum and archive. I want to thank Professor Peter Bartsch at the Johannes-Müller-Institut and Professor Peter Schneck at the Institut für Geschichte der Medizin at the Humboldt-University for all of their assistance during my stay in Berlin. I am thankful to Professor Wolfgang Eckart, Director of the Medizin-Geschichte-Institut for his helpful guide to the Heidelberg University's archive, and to Professor Klaus Maas at the Organische-Chemie-Institut for access to the collection of historical instruments and valuable discussion on Bunsen's laboratory at Heidelberg University. I want to thank Professor Michael Hubenstorf for his advice on the initial stage of my thesis and his helpful assistance during my work in the Vienna archives.

I would like to thank Professor Valentina Fedorovna Novodranova, my doctoral thesis supervisor and mentor at the Moscow Medical Academy (former 1st Meditsinskii Institut), for friendship and confidence in me. I owe a special debt to my family – my mother, husband and son for all their love and sympathy.

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Introduction

The thesis discusses the rise of the laboratory in Russian physiology. In particular, it studies the role that Ivan Mikhailovich Sechenov (1829-1905) and some of his colleagues and collaborators played in the introduction of radically new teaching fields such as experimental physiology and laboratory-based clinical training into the curriculum of Russia's leading military medical institution, the St. Petersburg Imperial Medico-Surgical Academy. Sechenov's later experimental research on blood gases and on salt solutions at St. Petersburg University is re-evaluated in terms of a gradual move from the experimental studies of physics and chemistry of the body to the specific problems of physical chemistry, necessitated by the growing complexity of methods and techniques applied in experimental physiology.

Why and how the laboratory became so dominant in modern medicine has received much attention in the last decade from both historians and sociologists of science. Cunningham and Williams suggest that the transition to laboratory medicine was a revolution comparable in importance to the transition to hospital medicine, which preceded it. The contributors to their volume have presented a picture of that revolution as a result of work in a number of traditions portraying intellectual, political, institutional, scientific and educational components of nineteenth century laboratory medicine.[1] I have aimed to integrate this multifaceted approach into my discussion of the rise of laboratory medicine in Russia. I argue that the arrangement and development of the first in Russia teaching-research physiological and clinical laboratories at the St. Petersburg Medico-Surgical Academy in the early 1860s was not a self-evident piece of

[1] A. Cunningham and P. Williams, "Introduction," in Cunnigham and Williams, eds, *The Laboratory Revolution in Medicine*, Cambridge, UK, 1992, pp. 3-6

progress imported from Germany but a crucial innovation introduced by a reformist administration of the Medico-Surgical Academy, led by the interests of the military. Since the Academy was the first to adopt the model of teaching-research laboratory, it set a precedent later emulated at other Russian universities, which proved significant for further spread and development of physiological and clinical research centers in Russia. I have shown how the military-medical authorities, who were convinced of the far-reaching benefits of the laboratory to the practice of medicine, funded and expanded the research and laboratory facilities at the Academy. The Ministry of Education, in contrast to the War Ministry, was more dependent on the constant disruptive changes of government policy toward higher education, and therefore was cautious and slow to support the university laboratory sciences.

Recent scholarship on nineteenth century physiology has examined the interplay among research programs, professional careers, institutional forms, medical practice and training, and state or social interests. It has also stressed the potential impact of physiological knowledge on health and disease that had become powerful enough to attract the interests of the political world.[2] My account of the modernization of the St. Petersburg Medico-Surgical Academy in 1857-1867 goes further, showing that the foundation of a number of specialized laboratories, in particular physiological, at the Academy, had become a matter of intense concern to the military world. The episode of transmission of the nascent German 'laboratory medicine' to Russia in the early 1860s demonstrates the readiness of the St. Petersburg military medical establishment to embrace as a whole the ideological shift towards the practicality of knowledge and the

[2] W. Coleman and F. L. Holmes, "Introduction," in Coleman and Holmes, eds, *The Investigative Enterprise. Experimental Physiology in Nineteenth-Century Medicine*, Berkeley, 1988, pp. 4-5

appreciation of the German movement to the expansion of natural sciences and their practical application that was expected to result in improved medical care for the army and other social benefits.

How did it happen, that in Russia unlike other European powers, it was the military-medical authorities who appeared at the forefront of the movement to the laboratory and 'scientific medicine' associated with it? In appreciating the role of the military in these matters it is necessary to look at the results of the major event of the period, the Crimean war (1853-1856) from two different but complementary perspectives: firstly, Russia's reform movement, crucial to the development of Russian science, medicine and education, and secondly, the radical change in her foreign policy that accelerated Russia's integration into the European scientific community.

The defeat in the Crimean war showed the basic deficiencies in Russia's power: an army system based on serfdom, the backwardness of her economy and her social structure. An enormous change in Russian society came with the emancipation of serfs in 1861 followed by the advancement of reforms in most of the institutions of society: educational, governmental and juridical systems. Alexander II and his government realized that the reforms should not undermine the autocratic system, the security of which rested on its most important pillar, the army. Military reform therefore became the main concern for the government. War Minister Count Dmitrii Milutin realized at the time that the army had to be equipped with the latest weaponry and required the construction of a railway network to sustain a mobility that in turn depended on industrialization. Moreover, a mass army required the conquest of cholera and typhus to ensure its health and that in turn depended on the development of medical knowledge and practices.[3]

Historians of nineteenth century Russian science have pointed to the importance of the reform period in the rapid growth of Russian scientific thought.[4] The 'national calamity' in the Crimea was interpreted by many enlightened high officials such as Dmitrii Milutin as well as scientists such as Nikolai Pirogov as the unavoidable result of Russia's backwardness in science and technology. Inadequate training in natural sciences and practical scientific knowledge, and disproportionate emphasis on classical education were the underlying cause.[5] After the Crimea the St Petersburg military-medical authorities followed the German model in educational matters: organization of the new natural sciences departments, and funding for the development of chemistry and experimental physiology, specifically modern teaching-research facilities such as laboratories with sophisticated equipment and devices. The reformist administration of the Academy attracted the best cadres such as I. M. Sechenov, S. P. Botkin, and later I. F. Cyon who were among the first Russians to gain scholarly reputation in the laboratories of Helmholtz, du Bois-Reymond, and Ludwig. I argue that Sechenov's career at the Medico-Surgical Academy (1860-1870) as well as Carl Ludwig's career at the Vienna Medico-Surgical Academy, Josephinum, (1855-1865) are representative of at least two factors: first, the crucial innovation in the military medical curriculum that was centered around introduction of the physiological laboratory, and second, the growing prestige of experimental physiology within the leading European military-medical

[3] The classical treatment of D. A. Milutin's military reforms is in P. A. Zaionchkovskii, *Voennye reformy 1860-1870 godov v Rossii [Military Reforms in Russia, 1860-1870]*, Moscow, 1952

[4] The exhaustive overview of the period is given in A. Vucinich, *Science in Russian Culture*, 2 vols, Stanford, California, 1970, v. 2, pp. 3-14; see also L. Graham, *Science in Russia and the Soviet Union, A Short History*, Cambridge, 1993, pp. 32-8

[5] On Pirogov's views see his article "Voprosy zhizni" ["Problems of Life"], first published in July 1856 in the journal *Morskoi sbornik [Marine Collection]*, in N. I. Pirogov, *Izbrannye pedagogicheskie sochineniia [Selected Pedagogical Works]*, Moscow, 1953, p. 56

institutions.

The most recent of the rich scholarship on the military campaign in the Crimea has been looking at the results of the Crimean war in terms of its repercussion on international relations.[6] For Russia, the Crimean war inaugurated a radical change in her foreign policy, which now played second fiddle to a domestic policy that began to be focused on overcoming economic, social, and scientific backwardness. Russia relinquished the role of 'gendarme of Europe' that she had held under Alexander I and Nicholas I, who had sustained and defended principles of solidarity among the European powers and the legitimacy of sovereigns. Instead, I argue, Russia after 1856 would now go about the development of her international scientific relations, and that meant for her first and foremost integrating into the European scientific community.

The liberalization of Russian academic life and free access to studies abroad were the first steps in that direction. Russia's openness to Western scientific influences followed by the successes in adapting the novel features and advanced methods in education and scientific research were rooted in the growing sentiments within the Russian intellectual community that the long awaited improvements in social life could be achieved through the development of scientific knowledge and its practical application to all spheres of human activities. Lenoir has pointed out the importance of the connections of the ideological shift: the 'discourse of practical interest' with the concept of progress and with the material improvement and industrialization of Germany.[7] The appeal to the need for a natural-scientific *Weltanschauung* and its

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[6] W. Baumgart, *The Crimean War 1853-1856*, London, 1999, p. 213
[7] T. Lenoir, "Laboratories, Medicine and Public Life in Germany 1830-1849. Ideological Roots of the Institutional Revolution," in Cunningham and Williams, eds, *The Laboratory Revolution in Medicine*, pp. 14-71 (33)

progressive impact on the society is best expressed in the writings of Russian scientists of the 1860s.[8] Sofia Kovalevskaia (1850-1891) who had studied mathematics at Heidelberg University and then in Berlin under the leading German analyst Karl Weierstrass (1815-97) recalled about the 1860s: "We were so exalted by all these new ideas, so convinced that the present state of the society could not last long, that the glorious time of liberty and general knowledge was quite near, quite certain."[9] Two other scientists of the 1860s, Sechenov and Botkin, also hoped to obtain advanced methods in teaching and research in Germany, and to apply and develop them in Russia. Their striving to maintain tight connections with the European research in medicine was an outgrowth of the Reform era of the 1860s.

The tradition of Russians traveling abroad for studies in medicine and natural sciences was established as early as the 1760s, but the number of Russian students in such centers for learning as Leyden, and later in Vienna and Paris, was few. In the first half of the nineteenth century the practice of sending graduates abroad for advanced studies by the government still had an unsystematic, episodic character and was highly dependent on the intricacies of Russia's foreign policies. The drastic change came after the Crimean war with realization of the strong argument in favour of Russia's integration into European scientific community. The War Ministry assigned a special

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[8] On the Reform described by the young Russian scholars from the vantage point of science, see Vucinich, *Science in Russian Culture*, v. 2, pp. 3-9

[9] Anna Carlotta Leffler and Sonia Kowalewski. *Biography and Autobiography*. Transl. L. von Cossel, New York, 1895, p. 11. On Sofia's studies with Weierstrass and their correspondence, see "Master and Pupil" in E. T. Bell, *Men of Mathematics*, New York, 1937, pp. 423-32. See also Sofiia's biography by Ann H. Koblitz, *A Convergence of Lives. Sofia Kovalevskaia: Scientist, Writer, Revolutionary*, Basel, Boston, 1983. Sofia arranged a fictitious marriage so that she might have an opportunity to study abroad. Her husband Vladimir Kovalevskii (1842-83), a zoologist and paleontologist, and his brother Alexander Kovalevskii (1840-1901), an embryologist, both were dedicated to scholarship, highly appreciated by Western colleagues and both were identified with the movement toward a social and intellectual emancipation of Russia.

fund for the Medico-Surgical Academy for establishing the systematic training of its graduates in the leading European research centers. That innovative practice, soon emulated by Ministry of Education, proved significant for the growth of a national scientific elite.

In the late 1850s Russian students outnumbered those from elsewhere at Heidelberg University. Heidelberg at that time was the most reputable center for teaching and research in natural sciences: it had its two famous laboratories, the chemical laboratory of Bunsen and the physiological of Helmholtz. Nikolai Zinin, one of the leading organic chemists and an influential member of the reformist administration introduced Bunsen's system of chemical education at the Medico-Surgical Academy. It consisted of a program of training in special research methods, such as gas analysis, the technique of titration of solutions and of reactions in sealed tubes under high pressure. These were particularly important for chemistry as well as for physiology. The simultaneous development of related disciplines, physiology, chemistry and physics, and their possible fruitful interactions, was an important step in the transition to the integrative approach to the medical research and teaching at the Academy.

A decade later, in the 1870s, Leipzig University was the leading European research center in experimental physiology and structural chemistry. Russians were the most numerous of the young researches there, in both Ludwig's physiological and Hermann Kolbe's chemical laboratories. Karl Rothschuh's family tree of Ludwig's students includes only prominent Russian physiologists. Among Russians, A. M. Zaitsev (1841-1910), V. V. Markovnikov (1837-1904) and N. A. Menshutkin (1842-1907) were all world-class chemists who made a great impact in Kazan, St. Petersburg, and Moscow during and after the life of their teacher A. M. Butlerov (1828-86), the leading structural chemist in Russia.[10]

Foreign Students in the Physiological and Chemical Laboratories at Leipzig University (1860-90) [11]

	Russia	Great Britain	Scandinavia	US	Austria	Switzerland
Ludwig's Laboratory	20	5	16	13	--	--
Kolbe's Laboratory	21	20	--	10	3	7

It was with foreign students that Ludwig as well as Kolbe had much of their educational fame; their Russian students were among the most successful in gaining academic positions and international renown for their research. In great measure the scholarly reputation and close connections of Sechenov and Butlerov with Ludwig and Kolbe were responsible for the presence and successes of their students in the laboratories of Leipzig University.

The role of scientific instruments in the intellectual and social changes associated with the rise of experimental physiology has attracted the attention of historians of

[10] Alexander Mikhailovich Butlerov (1828-86), an organic chemist, professor of chemistry first in Kazan and then in St. Petersburg Universities. In 1858 Butlerov studied at Adolph Wurtz's laboratory in Paris, and in Heidelberg, where he got acquainted with August Kekulé (1829-96). In 1861 Butlerov proposed the term *chemische Struktur* in place of Charles Gerhardt's 'constitution' to mean that the particular arrangement of atoms within a molecule was the *cause* of its physical and chemical properties, and assumed the tetrahedral arrangements of carbon valencies. He also investigated isomeric isodibutylenes, recognizing the existence of isomeric change. The English language sources on Butlerov are A. J. Rocke, *The Quiet Revolution. Hermann Kolbe and the Science of Organic Chemistry*, Berkeley, 1993, pp. 257-9, 261-4; W. H. Brock, *The Norton History of Chemistry*, New York, 1993, pp 256-60; M. Nye, *From ChemicalPhilosophy to Theoretical Chemistry*, Los Angeles, 1993, pp. 101-2

[11] For Ludwig's laboratory, see K. Rothschuh, G. Risse, ed. and transl., *History of Physiology*, New York, 1973, p. 210; for Kolbe's laboratory, see Rocke, *The Quiet Revolution*, pp. 319-21

physiology.[12] Yet there is still considerable scope for studies of experimental practice in physiology and the specific techniques and apparatus that rendered that practice possible and effective. An examination of the physiological apparatus of the second half of the nineteenth century starting with inventories of the laboratory and expanding to analytical accounts of the research and teaching that centered around the particular instruments and apparatus is desirable especially in view of the attention given to experimental practices in other natural sciences such as physics and chemistry. The most recent volume on instruments and experimentation in the history of chemistry, edited by Holmes and Levere moves chemical instruments and experiments into the foreground of historical concern focusing on such themes as change and stability, precision, the construction and transformation of apparatus, the dissemination of instruments, and the bridging of disciplines through instruments.[13]

These issues are relevant and important for my discussion of the dissemination of German experimental physiology to Russia. The highly interdisciplinary practices of experimental physiology and physiologically oriented clinical medicine required a new generation of researchers that came to the scene in the mid-nineteenth century: those with a solid background in mathematics, physics, including electricity, and chemistry. The complex nature of the problems related to chemistry and physics of the living organism required bringing together traditions of research from these sciences. These

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[12] M. Borell, "Instrumentation and the Rise of Modern Physiology," *Science and Technology Studies* (1987) 5(2): 53-62; R. Frank, "The Telltale Heart: Physiological Instruments, Graphic Methods, and Clinical Hopes," in Coleman and Holmes, eds, *The Investigative Enterprise*, pp. 211-90; F. L. Holmes and K. M. Olesko, "The Images of Precision: Helmholtz and the Graphical Method in Physiology," in M. N. Wise, ed, *Values of Precision*, Princeton, 1995, pp. 198-221; T. Lenoir. "Models and Instruments in the Development of Electrophysiology, 1845-1912"in *Historical Studies in the Physical and Biological Sciences*, University of California Press, 1986, pp. 1-54

[13] T. H. Levere and F. L. Holmes, "Introduction: A Practical Science," in F. L. Holmes and T. H. Levere, eds, *Apparatus and Experimentation in the History of Chemistry*, Cambridge, Mass., 2000, p. xiv

accordingly demanded a precision and accuracy that forced physiological experimental practice to adopt the style of the exact physical sciences and improved instrumentation and methods. Like his teachers in Germany, Helmholtz, du Bois-Reymond and Ludwig, Sechenov exemplified the new generation of physiologists whose experimental skill and dexterity in devising instrumentation were well fitted to the demands of handling physiological problems of increasing complexity and to the dominant role of apparatus in these practices.

The new type of physiology Sechenov was introducing into the Russian educational system depended on and was defined by a specific set of instruments and methods, derived from physics and physical chemistry. The application of these methods to such physiological phenomena as nerve-muscle excitation and blood gases and the devising of new instruments or adapting the existing ones to new purposes was crucial for pursuing that kind of physiological inquiry. Studying Sechenov's design of the blood gas pump and its refinement along with his improvement of the absorptiometric method allows us to trace how the problems of respiratory physiology and blood gas research were elucidated experimentally and theoretically. More importantly, it also allows us to see how a particular method, in our case, gas analysis, and a particular apparatus, the gas pump, permeated experimental practice in related fields, and how they were conducive to cross-disciplinary discourse with its exchange of concepts, methods and instrumentation.

The dissertation looks at the material culture of a physiological laboratory of the time in the Josephinum in Vienna, in Leipzig Physiological Institute, and at the St. Petersburg Medico-Surgical Academy: the equipment of the laboratories, availability of apparatuses, appliances, major German and Austrian workshops in which physiological instruments were ordered and made for the laboratories. One of the best illustrations to the history of physiological instruments and methods is Ilia Cyon's *Atlas zur Methodik der physiologischen Experimente und Vivisectionen* published in 1876 in St. Petersburg and Giessen. Most of fine illustrations in the *Atlas* were pictures of instruments collected by Cyon for the laboratory of the St. Petersburg Medico-Surgical Academy during 1872-74 after Cyon had succeeded Sechenov. The picture that emerges from my account of the instrument collection of the Academy's laboratory is not only a glimpse of how a standard physiological laboratory in Russia and Germany was equipped. More importantly, it presents the other side in the perception of the physiological laboratory and its practices, the "costly ghastly kitchen," as Latour calls it, versus the image of its fine and sophisticated tools that facilitated and controlled experimenter's skills. The essential part of Sechenov's and later Cyon's work in the laboratory was the arrangement of the lecture-demonstration. These were important innovations not only for the Academy but also for the medical education system in Russia and proved significant for the institutionalization of experimental physiology in Russia. The appeal of the leading St. Petersburg physiologists, Sechenov and Cyon, to the importance of scientific instruments and techniques, of lecture-demonstrations that put the appropriate instruments at the center of experimental arrangement, of their detailed description in promotion of laboratory based medicine can be interpreted, as Jardine suggests, as aesthetic and rhetorical rather than practical accomplishment.[14]

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[14] N. Jardine, "The Laboratory Revolution in Medicine as Rhetorical and Aesthetic Accomplishment" in Cunningham and Williams, eds, *Laboratory Revolution in Medicine*, pp. 307-9

The major site for such a pursuit was a university laboratory where a physiologist could prepare for lecture demonstrations, and carry out his private research simultaneously training a small group of advanced students, who followed the specific task of their mentor. Historians of nineteenth century German physiology and chemistry have pointed to the importance of the small private-research university laboratories such as the laboratories of Johann Purkynje at Breslau, Johannes Müller, Gustav Magnus and Heinrich Rose at Berlin in the transition to the first large-scale university-supported institute laboratories that began to appear in the 1870s.[15] In the late 1850s, with the setting up the small teaching and research laboratory of du Bois-Reymond, and the physiological chemistry laboratory of Hoppe-Seyler at the Charité Pathological Institute of Virchow, Berlin University came to be seen as the center for training advanced medical students in experimental physiology. The research carried out in these laboratories represented two distinct investigative streams that both derived from physical sciences. Electrophysiology was oriented around electromagnetic phenomena and new methods of quantification and precision measurements with appropriate devices, while physiological chemistry derived its methods and instruments from the developments of organic and physical chemistry.

Sechenov was certain that the German mode of research and teaching was strikingly innovative. The small laboratory of du Bois-Reymond which centered around a particular set of electrophysiological devices and instruments with a clearly focused research agenda pursued by a few advanced enthusiastic students proved to be easily

[15] R. S. Turner, "Justus Liebig versus Prussian Chemistry: Reflections on Early Institute Building in Germany," *Historical Studies in the Physical Sciences* (1982) 13: 129-62; T. Lenoir, "Science for the Clinic: Science Policy and the Formation of Carl Ludwig's Institute in Leipzig," in Coleman and Holmes, eds, *The Investigative Enterprise*, pp. 139-43; W. Coleman, "Prussian Pedagogy: Purkynje at Breslau, 1823-1839," *ibid*, pp. 16-28; A. Rocke, *The Quiet Revolution*, p. 28

patterned and 'transported' to Russia by Sechenov. At its core stood du Bois-Reymond's electrophysiological methods and apparatus, powerful tools used for research and teaching and for fascinating illustrative experiments at the lectures. For Sechenov that became the emblem of the new physiology, which dealt with physics and chemistry of the body, and that came to be representative of Sechenov's laboratory practice during his entire career. In the following chapters we will see that electrophysiological devices were an essential part of his experimental arrangement and a central feature of all three of his laboratories: at the Academy, and later at Novorossiisk and St. Petersburg Universities.

For S. P. Botkin, a future key professor in clinical medicine at the Academy, the systematized and well-planned training and research in physiological chemistry in Hoppe-Seyler's laboratory embodied an important link between science and the clinic: chemical analysis of bodily fluids as a new diagnostic method rendered the art of healing quantitative thus transforming it into an exact science. 'Physiological medicine' which by that time had been clearly articulated by Carl Wunderlich as strictly scientific relied on new methods of investigation: graphic, microscopic and chemical. Ludwig Traube's teaching and research mode with its experimental strategy within clinical context became a model that Botkin would follow in his medical practice. Furthermore Traube's clinic with its orientation towards laboratory-based investigations of the disease served as a model for Botkin later at the Academy. As a clinician with physiological training in the laboratories of Carl Ludwig and Claude Bernard, Botkin fully appreciated the importance of the acquaintance of students in the clinic with laboratory methods and appropriate physiological and chemical instrumentation and devices that made it possible to train scientifically educated physicians. Botkin's preference for the Berlin model of clinical medicine and clinically oriented research model at the Pathological Institute of Virchow is illustrative of the growing ascendance of German medicine over the once famous Paris and Vienna schools mainly because of the integration of the laboratory into clinical practice. Botkin's important innovation in the clinic was the construction of a specialized laboratory equipped with physiological and chemical devices and instruments for diagnostic and research purposes. An essential part of his teaching program was to provide training in microscopic analysis, elementary chemical tests and physiological procedures, which in turn implied knowledge of basic methods and techniques of such laboratory sciences as chemistry and experimental physiology.

In contrast to the rather thin historiography on Botkin[16] and on Cyon,[17] Sechenov has been favoured with a particular attention from historians of physiology and

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[16] The most widely used source on Botkin has been the biography and recollections by his close friend, Belogogolyi: N. A. Belogolovyi, *Botkin, ego zhizn' i vrachebnaia deiatel'nost' [Botkin, his Life and Activity as a Physician]*, Moscow, 1892 and idem, *Vospominaniia*, Moscow, 1897. Their correspondence is published in N. Sadovskaia, *Perepiska S. P. Botkina s N. A. Belogolovym. Zapiski otdela rukopisei Vsesoiuznoi biblioteki im. Lenina [Correspondence of S. P. Botkin and N. A. Belogolovyi. Transactions of the Department of Manuscripts of the State Library after Lenin]*, Moscow, 1939. Botkin's biography, a volume in a popular Russian series *Zhizn' zamechatel'nykh liudei [The Life of Remarkable People]* by E. Nilov, *Botkin*, Moscow, 1966, is written in a fictional style and does not contain any references or any traces of research in the history of science. The same is true for an assessment on Botkin in M. L. Ravich, *The Romance of Russian Medicine*, New York, 1937 (247-55) and in W. H. Gannt, *Russian Medicine*, New York, 1937. The most notable works that attempted to define Botkin's clinico-physiological thinking and its influence on the development of Russian therapeutic school is D. D. Pletnev, *Russkie terapevticheskie shkoly [Russian Therapeutic Schools]*, Moscow-Petrograd, 1923. Botkin's interest in the influence of the central nervous system on visceral function is treated in F. P. Borodulin, *Botkin i nevrogennaia teoriia meditsiny [Botkin and the Neurogenic Theory in Medicine]*, Moscow, 1949. Of interest is a short account on Botkin's clinical school versus the school of empirical medicine of the notable Moscow clinician G. A. Zakhar'in (1829-1897) in V. O. Samoilov, *Istoriia Rossiiskoi meditsiny [A History of Russian Medicine]*, Moscow, 1997 (116-21). A useful account on Pavlov's work in Botkin's laboratory for animal experiments in pharmacology is found in the most recent English language scholarship on Pavlov, D. P. Todes, *Pavlov's Physiological Factory. Experiment, Interpretation, Laboratory Enterprise*, Baltimore, 2002, pp. 297-302

[17] Although Cyon's accomplishments and his influence on the development of Russian physiological school is mentioned frequently in Soviet and Russian historiographies, there is still no full-length biography of Cyon. Some attempts have been recently made to fill this gap, e.g.: N. M. Artemov, *Ilia Faddeevich Tsion. Kratkaia biografiia [I. F. Cyon. A Short Biography]*, Nizhnii Novgorod, 1996. The most valuable source on Cyon's activity at the Medico-Surgical Academy is still L. Popel'skii,

psychology, both Soviet and Western. In these fields Russia has a rich tradition that originated from Sechenov's famous discovery of a specific inhibitory center in the brain in 1863 and his neurophysiological researches associated with that discovery. Brief assessments of Sechenov's theory of the central nervous inhibition are included in two comprehensive histories of psychology.[18] Interest in Russian physiological psychology among Western historians of science continued, and became especially pronounced in the 1980s. These largely discuss Sechenov's physiological determinist approach to psychology, and his popular essay "Reflexes of the Brain," associated with the radical ideology of the time.[19] Mary Blazier in her discussion of the 'The Great Russian School of Physiology' regards Sechenov as an important figure in nineteenth-century neurophysiology, whose experiments "were to suggest to him a concept of brain mechanisms later to flower in the hands of Pavlov into the theory that has dominated Russian neurophysiology ever since."[20] In general, Sechenov's a role as a precursor of I. P. Pavlov was a favourite *leit-motif* in both Russian and Western historiographies of the 1980s, that tended to stress Sechenov's neurophysiological contribution and linked it to politico-ideological issues.

Istoricheskii ocherk kafedry fiziologii v Imperatorskoi Voenno-meditsinskoi akademii za sto let, 1798-1898, St. Petersburg, 1889, pp. 69-93. An interesting and useful account on Cyon's influence on Pavlov is found in A. S. Mozzhukhin and V. O. Samoilov, *I. P. Pavlov v Peterburge-Leningrade*, Leningrad, 1977, pp. 25-44 and also in D. Todes, *Pavlov*, pp. 50-7. Western scholarship on Russian psychology has treated Cyon primarily from politico-ideological standpoint, e.g. D. Joravsky, *Russian Psychology: A Critical History*, Oxford, 1989, pp. 70-7

[18] R. B. Livingston, "How Man Looks at his Own Brain: An Adventure Shared by Psychology and Neurophysiology," in S. Koch, ed., *Psychology: A Study of a Science*, 4 vols, New York, 1962, v. 4, pp. 51-99; F. Fearing, *Reflex Action: A Study of the History of Physiological Psychology*, New York, 1964, pp. 191-4

[19] D. Todes, "From Radicalism to Scientific Convention: Biological Psychology in Russia from Sechenov to Pavlov," Doctoral diss., University of Pennsylvania, Philadelphia, 1981; J. Brett "Materialist Philosophy in 19th Century Russia: The Physiological Psychology of I. M. Sechenov," Doctoral diss., University of California, Los Angeles, 1975

[20] M. Blazier, *A History of Neurophysiology*, New York, 1988, p. 52

David Joravsky, however, thinks that his treatment of Sechenov is different, far from the conventional "tale accepted by Western as well as Soviet scholars." He states, in particular, that belief in a natural alliance of radical ideology and physiological science that was wide spread in the 1860s, had faded in the following decades, but revived in the post-revolutionary period, as part of a mentality that came to be called Stalinist. That is exactly the same well-known Soviet "tale," but with different accent and terminology. Joravsky harshly criticizes Iaroshevskii, a historian of psychology and the major Soviet biographer of Sechenov, as the auther of a partisan distortion assigning Sechenov the role of prophet for some twentieth-century school. Arguably, Joravsky insists that bold young Sechenov suffered defeat at the messy boundary with psychology, and retreated from the research on neural network to largely unproductive studies of gas absorption.[21] The most recent scholarship on the history of mind and brain sciences treats Sechenov in a balanced way, as a physiologist who sharpened the focus of nineteenth-century neurophysiological research on the problem of central nervous inhibition, and relates him to the European debate on inhibition, one of the major topics in nineteenth and early twentieth-century physiology and psychology.[22]

The most important among Western scholarship on the development of scientific thought in Russia during the turbulent 1860s up till the end of the century, is Alexander Vucinich *Science in Russian Culture*. The volume contains a broad intellectual construct and emphasizes the distinctive social and cultural attributes of nineteenth-century Russian science. It also examines individual scientists and scientific institutions within the relationship between the values of scientists and the dominant values of Russian

[21] Joravsky, *Russian Psychology*, pp. 53-4, 133, 129
[22] R. Smith, *Inhibition: History and Meaning in the Sciences of Mind and Brain*, Berkeley, 1992

culture.

Vucinich rightly points to the difference between Sechenov, who was directly identified with a philosophy of scientific materialism, and the major architects of Nihilism, N. A. Dobroliubov (1836-61), N. G. Chernyshevskii (1828-1889), and D. I. Pisarev (1840-68).[23] For them science was an ideological weapon for attacking the foundations of the existing social system, that should be modernized according the principles and methods of natural science. The Nihilists were particularly interested in modern physiology. They were impressed with the claim of the French positivist philosopher Auguste Comte (1798-1857) that a rigorous physiological study of the brain could suggest valuable clues to the inner pulses of human social life. They were also influenced by the scientism of the German materialists Jakob Moleschott (1822-93), Ludwig Büchner (1824-99), and Karl Vogt (1817-95), who maintained that consciousness like other social phenomena was a direct consequence of physiological processes; identifying psychic and somatic, they stated that thought is secretion of the brain.[24] For the Nihilists, Sechenov, who attempted to explain all man's psychical acts as reflexes, embodied intellectual emancipation from the official ideology with its outdated and false principles of morality and religion, which they so ardently attacked.[25]

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[23] Vucinich, *Science in Russian Culture*, v. 2, p. 120

[24] The term 'nihilists' was first used by I. S. Turgenev (1818-83), famous Russian writer, in his novel *Otsy i deti*, published in 1862. Lenin who highly valued the radicals of the 1860s preferred to define their philosophy as 'materialism of revolutionary democrats.' On philosophical sources of the Nihilism, see *Filosofskii slovar,'* I. F. Frolov, ed., Moscow, 1987, pp. 270, 321; on 'vulgar materialism' see, *ibid*, pp. 78-9; see also Vucinich, *Science in Russian Culture*, pp. 14-5

[25] Like the Nihilists, Sechenov was an advocate of higher education for women. In 1861 several girls were enrolled at the Medico-Surgical Academy. One of them Maria Bokova (1839-1929, born Obrucheva), a daughter of a landowner and general, arranged a fictitious marriage with the physician P. Bokov to become independent from her parents. In 1861 she became Sechenov's wife. He supervised her first research work in colour vision. Maria got her M.D. from Zurich University. Only after official divorce in 1888, they could register their marriage and had a wedding ceremony in the church. See P. G. Kostiuk, S. P. Mikulinskii, M. G. Iaroshevskii, eds, *I. M. Sechenov. K 150-letiiu so dnia rozhdeniia [I. M. Sechenov. 150 Anniversary]*, Moscow, 1980, p. 555

However, the Nihilists, armed only with the philosophical doctrines and mastery of ideological arguments, and Sechenov, with his solid knowledge of the natural sciences and experimental methods and techniques, represented completely different perceptions of complex physiological phenomena. Never (at least, to my knowledge) in his popular writings that were a model of fine scientific style, did Sechenov elaborate on the Nihilist philosophy and never did he refer to its famous adepts. Later in his *Autobiographical Notes* Sechenov wrote: "Because of this book I have been accused of being an involuntary propagator of immorality and nihilistic philosophy. Unfortunately, the censorial rules of the time prevented my publishing a straightforward explanation. Such an explanation would at once have put an end to the misinterpretation of my words."[26]

Nevertheless, Sechenov, more than anyone else among the notable scientists of his generation was associated with challenge to the official ideology. The biologists Mechnikov and Alexander Kovalevskii, with whom Sechenov worked in Novorossiisk University in the 1870s, believed in the rational orientation of science. Although A. Kovalevskii was confident that science and politics could not exist in absolute isolation, he nevertheless did not elaborate on this idea in his published papers,[27] whereas Mechnikov was an advocate of the full separation of science and politics. Later Mechnikov recalled that he had to leave the country in view of the growing political upheaval at Russian universities.[28] Sechenov's friend, Mendeleev, rejected the vulgar

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[26] Sechenov, *Autobiographical Notes*, p. 110. A discussion on the censorship is found in D. Todes, "Biological Psychology and the Tsarist Censor: The Dilemma of Scientific Development," *Bulletin of the History of Medicine* (1984) 58: 529-44

[27] V. L. Omel'ianskii, "Razvitie estestvoispytaniia v Rossiii v posledniuiu chetvert' veka" ["The Development of the Natural Sciences in Russia in the Last Quarter of the Century"] in *Granat- Istoriia. Istoriia Rossii v 19 veke,* 9 vols, Moscow (n. d.): 116-44 (137). On A. Kovalevskii's work and its significance, see I. I. Mechnikov, *Stranitsy vospominanii [Pages of Memoirs]*, Moscow, 1946, pp. 14-44

[28] Mechnikov, *Stranitsy*, pp 79- 84. The most widely used source on Mechnikov has been the biography by his wife, published in France in 1919 and translated into English, German, and Russian: O.

materialism of Büchner, Vogt and Moleschott, openly criticizing the nihilists. At the same time he appreciated scientific efforts to explain psychological phenomena in physiological terms. Mendeleev's "materialism" never transcended a purely scientific interest in atomism. P. L. Chebyshev (1821-94), another of Sechenov's colleagues in St. Petersburg University, the most distinguished Russian mathematician of the 1860s and 1870s, represented a cold, logically involved, and ideologically neutral science that was not attractive to the radical intellectuals.[29]

Sechenov, Botkin, Mendeleev, and Mechnikov like the majority of Russian scientists of the time, with few exceptions (e.g. S. Kovalevskaia and V. Kovalevskii), were "conservative liberals": they opposed any revolutionary changes in the structure of Russian polity and society, and on the other hand, they maintained that the future prosperity of the country depended on fundamental democratic reforms in all spheres. But because of Sechenov's interest in the problem of consciousness and free will and his public pronouncement of his views, it was easy for the Soviet historians of science to overemphasize Sechenov's involvement (even passive) in the radical movement of the 1860s and his connections (although doubtful) with the adepts of the Nihilism. It was also easy to squeeze Sechenov's views on the mind and body problem into the Procrustean bed of dialectical and historical materialism, the cornerstone of Soviet orthodoxy. Not surprisingly then, Sechenov's more ideological neutral contributions to other areas of nineteenth-century physiology, such as electrophysiology and blood gas

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Metchnikoff, *The Life of Elie Metchnikoff*, trans. E. R. Lankester, London, 1921

[29] On Mendeleev and the Nihilist philosophy, see Vucinich, *Science in Russian Culture*, v. 2, p. 160-1; on the Nihilists and mathematics, see *ibid*, p. 166; on Chebyshev's school in mathematics see excellent study: A. D. Alexandrov, A. N. Kolmogorov, and M. A. Lavrent'ev. eds, *Mathematics: Its Content, Methods, and Meanings*, trans. S. H. Gould, 3 vols, Cambridge, 1963, v. 2, pp. 259-68

research, and to physical chemistry, are completely missing from the extensive Soviet historiography on Sechenov.

Sechenov's career has been well documented, the most widely used source has been the biography by Shaternikov, published in 1935 and translated into English.[30] The other well-known biographies of Sechenov are by Koshtoyants and Iaroshevskii.[31] Koshtoyants's volume is typical of the Soviet genre of a scientific biography: all biographical matters are presented in clichéd oppositions: conservative versus progressive, Western versus Russian, religious versus scientific, idealistic versus materialistic. Of course, Sechenov represents the enlightened view of world revolutionary struggle, and of course, the author expressed mandatory gratitude to Comrade I. V. Stalin for inspiration and for the attention to the history of the natural sciences. However, Koshtoyants, a noted physiologist and historian of medicine, comprehensively considered not only Sechenov's neurophysiological researches but also his physico-chemical studies on blood gases, as well as the investigation Sechenov undertook in connection with the tragic end of the French balloonists on the "Zenith" in 1875. Koshtoyants used archival sources extensively and was the first to publish Sechenov's letters from Graz to Maria Bokova. Another volume by Koshtoyants, *Ocherki*, provides some useful information on the history of experimental physiology in Russia.

Iaroshevskii's biography of Sechenov is not the result of studies of Sechenov's experimental research in physiology, to say nothing of physiological and physical

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[30] M. N. Shaternikov, "The Life of I. M. Sechenov," in I. M. Sechenov, *Selected Works*, Shaternikov, ed., Moscow, 1935, pp. vii-xxxvi

[31] Kh. S. Koshtoyants, *I. M. Sechenov. 1829-1905*, Moscow, 1950; idem, *Essays on the History of Physiology in Russia*, D. B. Lindsley, ed., D. P. Boder, K. Hanes, and N. O'Brien, trans., Washington, D. C., 1964. M. G. Iaroshevskii, *Ivan Mikhailovich Sechenov (1829-1905)*, Leningrad, 1968

chemistry. The author has limited himself to more narrow goals clarifying Sechenov's views on psychology and the critique of different kinds of philosophical idealism. Iaroshevskii sees as the most striking feature of Sechenov's personality, his complete and ardent preoccupation with the questions of psychology. Sechenov's relation with the radicals is the dynamic axis of the book. How little this approach might elucidate Sechenov's scientific contribution to the development of the laboratory in Russia we recognize in the following chapters. In addition one can easily note that Iaroshevskii's own philosophical erudition is limited to the most trivial declarations of "official materialism," with references to Lenin whenever possible.

There are numerous articles in Russian describing Sechenov. These largely discuss the *Reflexes of the Brain* as the basis for Sechenov's psycho-physiological views and their significance, as well as problems concerning his theory of central nervous inhibition and historico-logical connection between Sechenov's and Pavlov's works in physiology of the higher nervous system. The articles do not provide any new orientation or information concerning the development of Sechenov's experimental research within a broader context of European experimental physiology, but again emphasize the philosophical and ideological significance of Sechenov's legacy. An example of this is the collection of essays by noted Soviet physiologists, psychologists and historians of biology and psychology. Published in commemoration of Sechenov's 150 anniversary and aimed at examining all aspects of Sechenov's scientific activity, the volume covers a variety of themes: from the interpretation of Sechenov's philosophy to the impact of his ideas on the developments in such areas as modern neurophysiology, aviation medicine, psychophysiology of the will, sensory systems, and functions of vision centers. The essential part of the volume comprises essays concerning the establishment of Sechenov's psychological concepts as well as the Russian-Soviet school of physiology.

However, the volume is useful as it catalogues extensively Sechenov's published works, and contains recollections by his contemporaries, secondary studies, and various footnotes of interest in a rather general and biographical study. Relevant essays for our purpose are those that attempt to define Sechenov's experimental studies in such areas as electrophysiology and physical chemistry within the institutional and scientific context. A. I. Roitback examines Sechenov's investigations in nerve-muscle physiology, however, a detailed analysis of the role of electrophysiological methods and instrumentation as the essential part in Sechenov's research program and his lecture-demonstrations is not developed.[32] The essay by S. A. Chesnokova, describes Sechenov's stay at the European laboratories, but Sechenov's perception of the German physiological laboratory, which proved decisive in his innovative activities in Russia, within a broader context of German experimental physiology of the time is lacking.[33] A comprehensive account on Sechenov's career at the St. Petersburg Medico-Surgical Academy is found in the essay by V. O. Samoilov.[34]

I have already mentioned that Sechenov's work on blood gases and salt solutions was brushed aside or even ridiculed by some Western historians who have discussed Sechenov.[35] Of course, Sechenov is now remembered mainly for his discovery of

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[32] A. I. Roitbak, "Vklad Sechenova v elektrofiziologiiu," in Kostiuk et al, eds, *Sechenov*, pp. 174-84
[33] S. A. Chesnokova, "Rabota Sechenova v fiziologicheskikh laboratoriiakh Germanii" ["The Work of Sechenov in German Physiological Laboratories"] in *ibid*, pp. 90-102
[34] V. O. Samoilov, "Sechenov v Mediko-Khirurgicheskoi Akademii," in *ibid*, pp. 103-33
[35] Joravsky says, "for the rest of his long life Sechenov would pump gas." Joravsky, *Russian Psychology*, p. 129

central nervous inhibition, an important step in the experimental studies of brain mechanisms. However, according to Shaternikov, who compiled a list of Sechenov's works in the late 1890s, out of 106 publications, 46 concern physico-chemical problems.[36] In Soviet historiography, except for the excellent article by the noted historian of chemistry, Iu. I. Solov'ev, there is scarcely any study of Sechenov's physico-chemical research.[37] Although Solov'ev provides the most complete single analysis of Sechenov's absorptiometric work on blood and salt solutions, his treatment is brief in regards to the debate on theory of solution between the two competing schools – the hydrationists led by Mendeleev and the ionists led by Ostwald, and the reception of Sechenov's absorptiometric methodology by both schools. Little attention has been given to the relationship between the different strands of Sechenov's physico-chemical investigations and to the placement of Sechenov's work within the development pf respiratory physiology in Germany and France. Chapter 3 of the dissertation examines these issues. Sechenov's experimental research on the composition of blood gases is an example of the application of quantitative chemical methods to a problem of scientific physiology. These studies during which he made improvements to the methods of a physicist, Heinrich Magnus and a chemist, Lothar Meier, were among his earliest and remained one of his major interests throughout his entire career, that eventually led Sechenov to the important contribution in the studies on salt solutions that were favourably received by the leading Russian and German chemists.

Rather than writing a biography of Sechenov, I have chosen to focus on his career as a research scientist on the grounds that it is the most relevant to the broader

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36 Koshtoyants, *Essays*, p. 214

37 Iu. I. Solov'ev, "O fiziko-khimicheskikh issledovaniiakh Sechenova" ["On Sechenov's Physico-chemical Researches"] in Kostiuk et al, eds, *Sechenov*, pp. 325-35

picture of the rise of the laboratory in Russian medicine during the second half of the nineteenth century. Sechenov was a laboratory scientist *par excellence* who spent his entire career at the laboratory and lecture hall. He set up several laboratories: the laboratory at the St. Petersburg Medico-Surgical Academy served as a model for two others, at Novorossiisk and St. Petersburg Universities. The laboratory of Sechenov's successor at the Academy I. F. Cyon and the clinical laboratory of Botkin continue the central theme, which runs throughout the thesis. The pattern stays the same: an outline of the new experimental program and the instruments and equipment needed to pursue it. Occasionally in the interest of clarity I will discuss a line of scientific investigations separately from the institutional context

In my treatment of Sechenov, I expand the circle of scientists concerned with the laboratory and scientific medicine both in Russia and Germany. I introduce a network of German physiologists with whose work and personalities Sechenov was to be involved throughout his career. Sechenov was also scientifically and personally engaged with the leading chemists of the period, including Borodin, Mendeleev, Butlerov, and Ostwald.

Scholars have lately been examining scientific styles or distinct 'cultures' of the institutional leaders in nineteenth century Germany, emphasizing the importance of rigorous apprenticeship in the development of creative talent.[38] Teaching and its relationship to research have not been ignored in the literature on scientific schools. Kathryn Olesko points out that the demands of the classroom shape traditions of research and stresses the role of tacit knowledge in understanding not only school

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[38] J. Fruton, *Contrasts in Scientific Style. Research Groups in the Chemical and Biochemical Sciences*, Philadelphia, 1990; for a recent discussion on national styles of scientific research see M. Vicedo "Scientific Styles: Toward Some Common Ground in the History, Philosophy, and Sociology of Science," *Perspectives on Science*, (1995), 3: 231-54; see also J. Harwood, *Styles of Scientific Thought. The German Genetics Community 1900-1933,* " Chicago, 1993

formation, but more generally the formation of the scientist. In his discussion of research schools and their histories Servos suggests that tacit knowledge of technique constitutes but a small part of what masters transmit to their disciples. Far more important, he further argues, may be the guidance that they offer on the problem structure of their discipline and the enthusiasm and inspiration through informal exchange and example.[39]

During his work at the Medico-Surgical Academy's physiological laboratory, Sechenov and a group of advanced students formed a 'school' in terms of their relationship: master and pupils were united by common research problems that were grounded in Sechenov's work on central nervous inhibition. However, the picture that arises from my analysis of Sechenov's laboratory practice at St. Petersburg University in the later period differs significantly: Sechenov set up the research program for his students in the traditional questions of nerve and muscle physiology, while he himself was deeply engaged solely in the experimental work on salt solutions. Was it a mere accident that none of Sechenov's students at the University was involved or at least interested in the absorptiometric studies of their master? Could Sechenov's decision to supply his students with problems solvable in limited time by predictable methods be explained by his awareness of the complexity of his research project on blood gases and salt solutions he was attempting to solve? We can attribute that partly to institutional barriers and severe limitations in funding, and partly to Sechenov himself: to his preference for a particular mode of organizing scientific work and training students for future independent work, which might be termed a peculiarity of his scientific style.

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[39] K. M. Olesko, "Tacit Knowledge and School Formation," in *Research Schools: Historical Reappraisals, Osiris* (1993), 8: 16-29; J. W. Servos, "Research Schools and Their Histories," *ibid*, pp. 3-15

The organization of the thesis is chronologically united by one theme that falls into two distinct stages in the development of experimental physiology in Russia: a mass exodus of young Russian scientists to the German laboratories in the early 1860s, followed by the assimilation of West European experimentalism, that was characterized by Russia's strong attachment to the European research centers and simultaneous development of her own scientific institutions.

The thesis is divided into three chapters. The first chapter sets the stage for studies abroad of the young Russian scientists during the early stage of the Reform era followed by Russia's defeat in the Crimean war. The scholarly successes of Sechenov, Botkin, Borodin, and Mendeleev in German laboratories and their connections with the European institutional leaders are exemplary in understanding Russia's gradual integration into the European scientific community. Sechenov's early investigations on blood gases in Vienna and Botkin's researches at the Berlin Pathological Institute are treated in detail. What influenced their choice to stay at one institution or another? What ideas and concepts, experimental skills, techniques and instruments did they seek to bring back home and in what way did these advantages affect their careers at home? The evidence is rich: I have used their letters written from abroad and their reminiscences about their studies as well as some of my findings in the archives. These images reflect both instant impressions and later reflections on the development of scientific medicine in Germany. I have sought to convey the flavor of those days and to capture the feeling of excitement that mixed art and science as new experiences for the young Russian scientists. I do not argue that images of French or German medicine rest exclusively on the impressions and motives of the Russian scientists, however, these evidences offer invaluable insights into the cultural specificity of scientific practices and professional milieu of nineteenth century European science. There is still no book-length study of the German impulse in Russian medicine,[40] although expressions of European influence on American physiology and medicine have been explored, particularly the French influence on American medicine.[41]

The second chapter analyzes the period of military reform at the St. Petersburg Medico-Surgical Academy and focuses on two major innovations: the setting up of physiological and clinical laboratories for teaching and research purposes. The laboratory leaders at the Academy, Botkin, Sechenov, and his successor, the distinguished physiologist I. F. Cyon, are treated in detail. Their researches during the most productive years from 1856 to 1886 were deeply rooted in the German physiological laboratories, in particular du Bois Reymond's in Berlin, Ludwig's first in Vienna and later in Leipzig, Hoppe-Seyler's in Strasbourg, as well as Bernard's laboratory in Paris. Although the particular research programs carried out at the institutions in Germany and France were linked to investigative activities pursued by Sechenov and later Cyon, the institutional arrangements in Russia were rather different. I take a cross-cultural and interdisciplinary approach to show how investigative practices were adapted to different local conditions as they moved form Germany to the Russian setting.

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[40] The exception is S. A. Chesnokova, "Osnovnye napravleniia i tendentsii razvitiia fiziologii Rossii i Germanii v XIX veke i russko-nemetskie nauchnye sviazi" ["The Main Trends and Tendencies in the Development of Nineteenth-Century Physiology in Russia and Germany and Russian-German Scientific Relations"], Doctoral diss., Institut normal'noi fiziologii im. P. A. Anokhina Akademii Meditsinskikh Nauk SSSR, Moscow, 1979

[41] J. H. Warner, *Against the Spirit of System. The French Impulse in the Nineteenth-Century American Medicine*, Princeton, 1998; on German impulse on American physiology see Robert G. Frank, "American Physiologists in German Laboratories, 1865-1914," in G. Geison, ed, *Physiology in the American Context, 1850-1940*, Bethesda, 1987, pp. 11-45

The third chapter focuses on Sechenov's physico-chemical work at the physiological laboratories of Novorossiisk and St. Petersburg Universities. This chapter deals with a set of scientific and experimental concerns that emerged in the early 1880s at the intersection of physiology and physical chemistry, and with novel scientific theories and experimental techniques. These were intensely experimental problems, each of which will be addressed in turn. One important historical puzzle concerns the transition in Sechenov's absorptiometric studies from experiments with blood to the investigation of salt solutions. M. N. Shaternikov, Sechenov's first biographer and those historians who followed him overlooked some essential features of etiology in Sechenov's investigations on salt solution. My account examines the interconnections between experimental physiology, primarily respiratory function of the blood, and chemistry of solutions, and the importance and relevance of the work of a trained physiologist to the larger picture of some aspects of the theory of solutions. I discuss Sechenov's research on the absorption of gases by salt solutions in terms of his attempt to construct a simple model in which water represented blood, establishing an analogy to the better understood area, particularly the hydration theory of solutions. The controversy over hydration between Mendeleev and the leading physical chemists Arrhenius and Ostwald creates a context for Sechenov's work on salt solutions, and I relate him to the European debate on the theory of solutions, a perspective that has not been developed elsewhere.

A rich variety of documents was available for my research. The main resources were selected published works of Sechenov and his colleagues and collaborators, Russian and German, which include diaries, correspondence, autobiographies, and obituaries. Archival materials include the minutes of the Conference of the Medico-Surgical Academy, of St. Petersburg University and University of Leipzig, and also official correspondence and records of War Ministries of Russia and Austria. The descriptions of particular experimental researches and instrumentation are taken primarily from the textbooks and selected monographs published during 1850-1880s by the leading German physiologists as well as by Sechenov and Cyon. I also used relevant material on nineteenth-century physiological instrumentation from Sechenov's Museum at the 1st Medical Institute (now the Medical Academy), the Berlin Medizin-historisches Museum, the Leipzig Karl-Sudhoff-Institut für Geschichte der Medizin, and the Berlin Johannes-Müller-Institut für Physiologie. These provide entry into most of the significant developments in nineteenth century scientific medicine.

With the new reign and with the conclusion of peace, all obstacles at once disappeared. The doors were wide opened, and all Russia rushed abroad. It was as if an entirely new world opened, full of charm and poetry, presenting realization of all my ideals. Wonders of nature and art, the educated mode of life of the countries that had left us behind on the way of enlightenment, science, and freedom, people and things – I craved to see all this by himself: I wanted fresh new impressions presenting human life in its height.

B. N. Chicherin, *Vospominaniia: puteshestvie za granitsu [Memoirs: Travel Abroad]*, Moscow, 1935, p. 21.[42]

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[42] Boris Nikolaevich Chicherin (1828-1904), professor of law at Moscow University (1861-1868), an Honorary Member of the St. Petersburg Academy of Sciences (1893), the author of numerous works on the history of state law and on political science. He was one of the most notable representatives of the liberal trend in Russian philosophic, juridical, and historiographical school of thought. His *Vospominaniia: puteshestvie za granitsu* published in 1928-1934 gives an interesting and original overview of the political, cultural, and academic life in Britain, Italy, France, and Germany in the mid-nineteenth century. Chicherin, a Russian aristocrat and liberal, accompanied the Grand Duchess Elena Pavlovna in her travel to Italy in 1856. Elena Pavlovna (1806-1873), a daughter of the Württemberg Prince Paul-Charles and a spouse of the Grand Duke Mikhail Pavlovich, was known for her salon where all distinguished figures of the St. Petersburg literary, musical, scientific, and liberal political circles were welcome. Notably, here in the 1850's the plans of the reforms that were realized in the 1860's and 1870's were under discussion. She was also known for her philanthropic activity: several hospitals and charity-homes were founded on her generous donations, as well as the community of sisters of charity during the Crimean war. During the next two and a half years of his trip throughout Europe, Checherin, an admirer of the constitutional monarchy system, visited sittings of the British Parliament, as well as some prominent historians and jurists in Berlin, Heidelberg, Munich, and Vienna. See Chicherin, *Vospominaniia*, pp. 30-33, 73-87, see also B. Iu. Ivanov et al. eds, *Istoriia Otechestva s drevneishikh vremen do nashikh dnei. Entsiklopedicheskii slovar' [History of Fatherland from Ancient to Modern Times. Encyclopedic Dictionary]*, Moscow, 1999, pp. 201, 452

Chapter I

German 'Scientific Medicine' in the late 1850's and early 1860's: a Russian View.

1. The Old-New Tradition

It was crucial for young Russian scientists of the generation of the 1860s that their early scientific and academic careers were unfolding in the period of the Great Reforms followed by Russia's defeat in the Crimean war. Abolition of serfdom, attraction of foreign capital to build a railway network that would develop industry and make the army mobile, the reforms of governmental and social structures - these were tremendous changes that marked a turning point in Russian history. For Russia in particular, the immediate aftermath of the war signified a great move to the modern world that was directly associated with industrialization and developments in technology and science both pure and applied. The poor state of Russian education and science that reached its point of crises under Nicholas I (1796-1855) changed dramatically after the humiliation of the Crimean war that provided an effective stimulus to the reforms of educational system.

There are a number of justifications for emphasizing the magnitude of these changes for the development of natural sciences in Russia during the second half of the nineteenth century. The essential element of these changes included liberalization of academic and cultural life that gave way to the moral sentiment within the Russian intellectual community that the long awaited improvements in social life could be achieved through developments in science and its practical application to all spheres of human activities. Russian intellectuals of the 1860s believed in the necessity of pursuing the challenging search for scientific knowledge that was correlated with Russia's openness to the influences of West European scientific and philosophic thought. That created a 'fertile soil' for adapting in Russia the most advanced scientific and medical ideas and practices, in particular, 'scientific medicine' and the laboratory associated with it.

The useful way to describe how these events came about is to discuss briefly the tradition of Russians' traveling to Europe for studies, for in a curious way the travels reflect both the attempts of the Russian rulers to maintain connections with enlightened Europe and their fears that the influx of Western liberal and humanistic ideas would undermine the autocratic order. The tradition of going abroad for knowledge that was introduced by Peter the Great (1672-1725), became prominent during the age of Catherine II (1729-96), whose early humanism and allegiance to French philosophers of the Enlightenment intensified the influx of western influences at all levels. The newly founded Moscow University and its two gymnasiums were too weak to satisfy the country's growing demand in professional manpower. Young Russians used to be sent to study medicine to Leyden, Edinburgh and Strasbourg, and law to Leipzig University, which at that time was a lively center for legal studies.[43]

In 1798, following the French Revolution and fearing the spread of its 'poisonous' ideas, Tsar Paul I (1754-1801) forbade Russians to study at any foreign

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[43] On Catherine's correspondence with Voltaire, d'Alembert, Diderot, and Madame Geoffrin see S. M. Solov'ev (1820-79), *Istoriia Rossii s drevneishikh vremen [History of Russia from Ancient Times]*, in 18 vols, Moscow, 1994, v. 13, pp. 469-475. On science, Enlightenment, and absolutism at the age of Catherine see Vucinich, *Science in Russian Culture*, v. 1, pp. 125-35

university in order to protect "immature minds of the Russian youth from unrestrained and corrupted reasoning."[44] Paul I was reacting against the policies of his mother, Catherine II, which in his opinion had 'impaired the foundations of absolutist power.' His son, Tsar Alexander I (1777-1825), following the course of moderate liberal reforms, in turn abolished his father's edict. Under Alexander I, Dorpat and Vilenskii University[45] were reopened and three new universities, in Kazan, Kharkov and in St. Petersburg were founded. Their model was Göttingen University famous throughout Europe for its academic autonomy and instructional freedom.[46] In the universities, most of the original research in science and the teaching was pursued by foreign scholars primarily German, who brought to Russia the newest scientific ideas and maintained Russia's intellectual connections with the European academic community.[47] During the second half of the nineteenth century Dorpat University was the most advanced among

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[44] *Polnoe sobranie zakonov [Complete Collection of Statutes],* v. XXV, N18474, cited in S. G. Svatikov, *Russische Studenten in Heidelberg. Unveröffentlichte Texte von S. G. Svatikov.* E. Wieschhöfer, ed., Heidelberg, 1997, p. 9. Sergei Griegor'evich Svatikov (1880-1944), a Russian jurist and historian, from 1906 a professor at the High Women's Courses at the St. Petersburg Polytechnic Institute, from 1911 at the St. Petersburg Higher Courses for Aesthetics, and from 1921, at Sorbonne. In 1940 he moved to the USA.

[45] Vil'no became part of the Russian Empire since 1795, now it is Vilnius, Lithuania. Vilenskii University was founded in 1641. The predecessor of Dorpat (Derpt) University was the *Akademia Gustaviana,* founded by the Sweden king Gustavus Adolphus (1594-1632) in 1632. Since 1893 till 1918 it was the Iur'evskii University, now the University of Tartu, Estonia. In the early nineteenth century Dorpat University was famous for its observatory and the instrument collection, at the time one of the most notable in Europe. Here taught professor of mathematics and astronomy, Wilhelm Struve (1793-1864), famous for his study of double and multiple stars. See M. Hoskin, ed., *Cambridge Illustrated History of Astronomy.* Cambridge, UK, 2000, pp. 216-17

[46] P. Milukov, "Universitety v Rossii" ["Universities in Russia"], in *Brockhaus-Efron* (1902) 39: 788-800 (p. 789)

[47] In Kazan University chemistry was taught by a notable German scholar Carl Claus, the teacher of Nikolai Zinin; mathematics, physics and astronomy was represented by four distinguished German professors Johan Bartels, Casper Renner, Felix Brunner, and Joseph Litton – all teachers of Nikolai Lobachevskii. On Lobachevskii see Vucinich, *Science in Russian Culture,* v. I, pp. 314-29. The classic treatment of the foreign scholars, "the giants of the St. Petersburg Academy of Sciences," see in *ibid,* during the eighteenth century, Leonard Euler, pp. 145-150; the embryologist Caspar Wolf, pp. 154-57, the naturalist and encyclopedist Peter Simon Pallas, pp. 150-54; during the first half of the nineteenth century - the astronomer Friedrich G. von Struve, the embryologist Karl von Baer, the physicist Henrich F. Lenz, and the analytical chemist Hermann Hess, pp. 295-304. Vucinich points out that the St. Petersburg Academy of Sciences of that period did not represent the status of "Russian science"; it represented the high status of science in Russia, *ibid,* p. 308

Russian universities, as it remained more open to the developments of European science. In 1828 Georg Friedrich Parrot (1767-1852), Rector of Dorpat University, professor of physics, later academician of the St. Petersburg Academy of Science initiated the founding of the Institute of Professors aimed at training professors for Russian universities. Parrot was a personal friend of Alexander I and was held in high esteem by Nicholas I. That might well explain their special attitude towards the independence of the Dorpat University.[48]

However, the shortage of instructors at the Russian universities and the lack of adequate libraries and research facilities such as physics and chemistry laboratories made the European universities the only places to get education in natural sciences. German universities traditionally remained places for the education of the Russian aristocracy and for those graduates of the Russian universities who were preparing for governmental services or academic careers in jurisprudence, state law, state history, philosophy and medicine. In the large centers for medical studies such as Vienna and Paris, Russians were not numerous compared to students from other countries, largely

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[48] The most talented graduates from various Russian universities were sent to the Institute of Professors. After two years of studies they were awarded the corresponding degree and, later, sent for another two years abroad for advanced studies. One of the first graduates of the professorial institute was N. I. Pirogov. On his studies in Dorpat, see N. I. Pirogov, *Voprosy zhizni. Dnevnik starogo vracha [Questions of Life. Diary of an Old Physician]*, G. Zarechnak, ed. and transl., Canton, MA, 1991, pp. 293-295. Written in 1881, Pirogov's *Questions of Life* is a revealing record of social and medical progress in nineteenth century Russia. It is also a valuable commentary on the universities and clinics where he had studied and worked as well as on the professional and intellectual milieu of the time. Here we meet his colleagues, nearly all notable Parisian and German surgeons and anatomists. In 1840 Pirogov was appointed Director of the Surgical Department of the Army Hospital and Professor of Hospital Surgery and Anatomy at the St. Petersburg Medico-Surgical Academy. His five volumes *Anatomia Topographica* (1843) was recognized as a useful tool of anatomical studies throughout Europe. During the Crimean war he served as consultant surgeon and head of special unit of women nurses. His rich wartime experience in Caucasus in 1847 and in the Crimea is reflected in his numerous works on field surgery, anaesthesia, and on Asiatic cholera, e.g. *Grundzüge der allgemeinen Kriegschirurgie* published in German in 1864. The literature on Pirogov is extensive, especially in Russian and German. See bibliography in G. Zarechnak, "Introduction to the English Edition" in Pirogov, *Questions of Life*. On Pirogov and the medical profession in Russia, see N. M. Frieden, *Russian Physicians in an Era of Reform and Revolution, 1856-1905*. Princeton, 1981, pp. 5-11; on the Pirogov Society, see *ibid.* pp. 118-22, 127-30

due to intricacies in the diplomatic and political relations with the Habsburg Empire and Napoleonic France.

The Russian government's policy towards foreign universities was contradictory and changeable, and depended heavily on Russia's role as the 'gendarme of Europe' in her foreign policy. During the first half of the of nineteenth century Russian rulers favouring the country's intellectual and cultural connections with Europe, nevertheless tried to avoid undermining the existing order and the threat to the autocratic power that was directly associated with Western ideological influences. In 1820-1823 Russians were forbidden to attend German universities in Heidelberg, Jena, Giessen, and Würzburg[49] as student unrest and liberalism were especially strong there. Alexander I was not suspicious of all German universities. He considered that the governments of Prussia and Hanover were on guard not to allow pernicious and harmful influences on youth, so Berlin and Göttingen universities were not ranked as dangerous.[50]

In the mid-1830s the Russian government sending their scholars abroad gave preference to the universities of Berlin, Göttingen, Giessen, and Heidelberg. According to Nikolai Ivanovich Pirogov (1810-81), who was sent to Germany in 1833 "all the medicos were supposed to go to Berlin, all natural scientists to Vienna, and all others (jurists, philologists, and historians) also to Berlin. For some reason, no one was

[49] Heidelberg University, the Grand Duchy of Baden, was founded in 1386; Jena University, Thuringia, in 1558; Leipzig University, the Kingdom of Saxony, in 1409; Giessen University, the Grand Duchy of Hesse, in 1607; Würzburg University, the Kingdom of Bavaria, in 1402 (1582); Göttingen University, the state of Lower Saxony, former Grand Duchy of Hanover, in 1737; and Berlin University, Brandenburg - Prussia, was founded in 1803. See R. A. Müller, *Geschichte der Universität. Von der mittelalterlichen Universitas zur deutschen Hochschule,* Munich, 1991

[50] On the reaction of the Russian government of Alexander I on the activities of *Burschenschaften* [student fraternities] and professorate, see Svatikov, *Russische Studenten,* pp. 13-7; on German response to radical nationalism in the 1820s, see M. Kitchen, *Cambridge Illustrated History. Germany*, Cambridge, UK, 1996, pp. 162-64

permitted to go to France and England,"[51] presumably because of the attraction of revolutionary ideas and of constitutional monarchy.

The revolution of 1848 in Europe led to the prohibition by Nicholas I of studies abroad, and to the severe restrictions within domestic universities. Strict censorship reduced the influx of Western scientific and philosophical literature.[52] In the words of the jurist and historian B. N. Checherin, a member of the "Moscow circle of Westerners" of the 1840s and 1850s, "since 1848 the Russian government made all possible difficulties for those daring to cross the holy borders of the fatherland... A traveler was considered a man who had partaken the fruits of enlightenment."[53] After the death of Nicholas I and Russia's defeat in the Crimean war, the situation changed drastically.

The repercussions of the Crimean war on the policy of the European great powers and on their mutual relations were great and far-reaching. The 'Concert of Europe,' which had been formed after the Napoleonic Wars in order to subdue revolutionary movements had to a large extent broken down. Among the first measures of the government of Alexander II (1855-1881) was the annulling of the restrictions for Russian students to study abroad. The procedure for getting travel documents was facilitated, and high prices for foreign passports were reduced.[54] That sparked the unprecedented exodus of young Russian scientists and students to the European centers of learning among whom Sechenov, Botkin, Borodin, and Mendeleev were to become

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[51] Pirogov, *Questions of Life*, p. 337
[52] On the reactionary policy of Nicholas I during the 1848 revolution in Europe and Russian universities see R. G. Eitmontova, *Russkie universitety na grani dvukh epokh [Russian Universities Between Two Epochs: the mid-19th Century]*, Moscow, 1985, pp. 58-61
[53] Chicherin, *Vospominaniia*, p. 21
[54] N. A. Belogolovyi, *Botkin*, p. 21

2. Berlin University: a New Center for 'Scientific Medicine'

Ivan Mikhailovich Sechenov (1829-1905) came from a family of provincial gentry. He was educated at home, where owing to the excellent instruction of Wilhelmina Konstantinovna Strom, the governess of his sisters, he was fluent in both French and German. During his studies at the St. Petersburg Military Engineering School (1843-48) he did not forget the languages, however his major interest at that time was the exact sciences:

> I had distaste for engineering and everything to do with it, physics was my favorite subject. In the junior officer class I conceived a liking for chemistry. I was good at mathematics, and had I entered the faculty of Physics and Mathematics at the University immediately after leaving the Military Engineering School, I think that I might have become rather a good physicist.[56]

But it was physiology of a kind, which required causal explanation based on physical and chemical principles that became his profession and a life-long sphere of his scholarly interests.

For his decision to retire from army service, which he entered after the Engineering School, Sechenov was indebted to a young lady from a family of his fellow-officer in Kiev. The young woman, Olga Aleksandrovna (her last name is unknown; we only know that she was a daughter of an exiled polish physician) eagerly discussed the rights of women and other social problems, and set a high value on science and intellectual work. She spoke of Moscow University as a center of culture and medicine as one of the noblest professions. In 1850, after one and a half years of service as an army officer, Sechenov entered the medical faculty of Moscow University.

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[56] I. M. Sechenov, *Autobiographical Notes*, D. B. Lindsley, ed., K. Hanes, transl., Washington, D. C., 1965, p. 17

The faculty was staffed with professors who had studied abroad before entering an academic career: N. E. Lyaskovskii, the professor of pharmacognosy, was a student of Justus v. Liebig at Giessen; A. I. Polunin (1820-88), the professor of pathological anatomy, was a student of Carl v. Rokitanski in Vienna; F. I. Inosemtsev (1802-69), the professor of surgery, had studied surgery at the Charité in Berlin; and I. T. Glebov (1806-84) the professor of anatomy and physiology, had studied under Johannes Müller and Theodor Schwann in Berlin. However, these were of the old type: none of them was actively engaged in research or publication. Much later in 1881 Botkin in a speech, dedicated to Rudolf Virchow, spoke critically about the way medicine had been taught in Moscow in 1850-1855: "The majority of our professors had studied in Germany. They more or less skillfully taught us what they knew; but such mode of teaching – in the form of catechism truths - could not inspire the eager minds of future researchers."[57] Sechenov in his *Autobiographical Notes* mentioned the poorly arranged lecture-demonstrations in the physiology course: the only experiments students were shown were insufflation of air in the veins of the dog, and pigeons with pinholes in the brain to describe disturbances in locomotion and changes in sensitivity caused by the operation. Confining himself to the French authors, Glebov said nothing at all in his lectures about the new physico-chemical trend in German physiology or about experiments on electrical stimulation of the nerve and muscle, although, according to Sechenov "Germany was long ago full of these experiments." Even the famous experiment on stopping the heart by stimulation of the vagus nerve was not mentioned.[58] However,

[57] S. P. Botkin, "Rech, proiznesennaia v obshchestve russkikh vrachei po povody iubileia 25 letnei professorskoi deiatel'nosti Rudolfa Virkhofa" in *Ezhenedel'naia klinicheskaia gazeta [Weekly Clinical Gazette]* (1881) cited in Belogolovyi, *Botkin*, p. 29
[58] Sechenov, *Autobiographical Notes*, pp. 47-8

Glebov lectured brilliantly in comparative anatomy, and his course on physiology reflected his admiration for the scientific work of Flourens and Bernard: during his studies in Paris, Glebov translated both Francois Magendie's *Précis Élémentaire de Physiologie* und Julius Budge's *Lehrbuch* [59] into Russian. But it was Johannes Müller's famous *Handbuch der Physiologie des Menschen* (1834) available from a German bookseller in Moscow[60] that sparked Sechenov's interest in German physiology. Therefore Berlin University where 'the celebrated Johannes Müller' taught became the most interesting and attractive place for Sechenov when after the graduation from Moscow he decided to study in Europe, using his mother's funds.

By the end of the 1850s, with the growing awareness of the vigor of some German universities in the field of natural sciences and medicine and with any foreign university readily accessible, quite a few Russians of ambition and means went to Germany for professional improvement. Equally important for the graduates was the advice of professors, who were well aware of the opportunities of participating in advanced scientific activities as well as of gaining practical experience with the European institutional leaders. Successful work at foreign laboratories or clinics with the publication of the original research results in European periodicals and completion of a doctoral dissertation were decisive for a successful academic career at home, for the respect of colleagues, and for recognition within a specialized scientific community.

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[59] Julius Ludwig Budge (1811-880), professor of anatomy and physiology in Bonn and then at the University of Greifswald (Prussia). For the discoveries related in his main work *Bewegung der Iris* (Braunschweig, 1855) Budge was awarded with the *Prix Montyon* of the Paris Academy of Sciences and prize of the Brussels Academy of Medicine. Other important works in the field of physiological and practical medicine were *Untersuchungen über den Einfluss des Centralnervensystems auf Bewegung der Blasé*, and *Über den Verlauf der Gallengänge (Gallencapillaren) in der Leber*. See *Neue Deutsche Biographie*, v. 3, p. 755

[60] The Diebner bookstore on Bol'shaia Lubianka street in Moscow. See Sechenov, *Autobiographical Notes*, p. 50

In Berlin, the Russian medical students formed a small colony: Sechenov, Botkin, L. A. Bekkers (1832-62), who had been a surgeon under Pirogov in the Sevastopol campaign, and an ophthalmologist E. A. Junge (1833-98). The effervescent Botkin became the life of the party and its leader. After studies, which continued from morning till six o'clock in the evening, the group often came together.[61]

In his letters from Berlin Botkin wrote with delight about the new Pathological Institute and its laboratory, and described the richness and accessibility of the 'treasures of Berlin University.' Botkin's brother wrote about it to his friend:

> The other day I got a letter from Sergei. What astonishing work is in full swing now in the European scientific world! And look at the path that modern medicine has chosen: microscopic analysis and chemistry are its foundation; everything is being verified by experiment and observation, absolute theories are being ridiculed. Sergei is awfully disappointed by the state of our medical education: how backward it is in comparison with what is now being done in Germany. On the whole, the surge in the field of natural sciences is quite remarkable in Germany. It has been restricted for so long by the exclusive predominance of philosophy. Imagine, philosophical lecture halls are absolutely empty, only about two or three listeners, truly 'the last of the Mohicans.' The lecture halls for natural sciences on the contrary are full.[62]

Botkin's brother Vasilii, one of the most educated men of his time, had noticed an interesting feature: the decline of philosophical fame of the University and the growing prestige of natural sciences. Berlin University was founded at the beginning of the nineteenth century by the Prussian philosophers and reformers Johann Gottlieb Fichte (1762-1814), Wilhelm von Humboldt (1767-1835), and Friedrich Schleiermacher (1768-1834). It represented a 'modern' model of broadly based education of human

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[61] Sechenov, *Autobiographical Notes*, pp. 70-1

[62] V. P. Botkin to P. V. Annenkov, letter d. Paris, 1856, cited in E. Nilov, *Sergei Petrovich Botkin*, Moscow, 1966, p. 42. Vasilii Petrovich Botkin (1811-1869), the oldest son in the family, was a well-known publicist and literary, music and art critic. See V. P. Botkin, *Literaturnaia kritika. Publitsistika. Pis'ma [Literary Critique. Publicism. Letters]*, Moscow, 1984

mind and spirit that was aimed to produce a spiritual elite of creative minds. Humboldt, who was inclined towards idealist philosophy and the intellectual intuition of Friedrich Wilhelm von Schelling (1775-1854) was succeeded as *Kultusminister* in the 1820s by Karl Freiherr Stein von Altenstein who was much influenced by Immanuel Kant's (1724-1804) emphasis on sense intuition and empiricism. The following years, Altenstein brought in a number of experimental scientists: Gustav Heinrich Magnus and the Rose, brothers Heinrich and Gustav, all students and collaborators of the brilliant bench and theoretical chemist Jöns Jacob Berzelius (1779-1848), and Johannes Müller.[63] Müller's emphasis on his adherence to the biological tradition of Kant and Goethe and his statement that observation and experiment were instruments for understanding the nature of life was responsible in great part for his appointment to both the philosophical and medical faculties.[64] The neohumanist reforms and the new *Wissenschaftsideologie* were associated with a strong commitment of the professoriate of Berlin University to research and publication combined with teaching.[65]

Historians of nineteenth-century German science have stressed the gradual changes, most significant in the natural sciences and medicine that led to less reliance on lectures and lecture demonstrations and eventually dictated laboratory instruction for

[63] D. Wendland, "Preussische Wissenschaftspolitik unter Kultusminister Altenstein (1770-1840) und die Berliner Universität," *Die Medizin an der Berliner Universität und an der Charité zwischen 1810 und 1850*, P. Schneck and H.-U. Lammel, eds, Husum, 1995, pp. 38-43; "Jöns Jacob Berzellius und die deutsche Chemie," in *Bunsen-Briefe in derUniversitätsbibliothek Marburg*, F. Krafft, ed., Marburg, 1996, pp. 61-71

[64] On Müller's philosophical commitments and his laboratory in Berlin, see B. Lohff, "...in Berlin eine würdige Stätte schaffen," *Die Medizin an der Berliner Universität*, Schneck and Lammel, eds, pp. 55-66; see also T. Lenoir, "Science for the Clinic" in Coleman and Holmes, eds. *The Investigative Enterprise*, pp. 146-48; and K. Rothschuh, *History of Physiology*, pp. 200-3

[65] An exhaustive study on German professoriate in the early nineteenth century and the research and teaching imperative see K. Schwabe, ed., *Deutsche Hochschullehrer als Elite 1815-1945*, Boppard, 1988

most students in the sciences.[66] These developments happened simultaneously in both chemistry and experimental physiology. In the early 1840s the wide-ranging researchers at Berlin University Gustav Magnus (1802-1870) and Heinrich Rose asserted a preference for the use of academic laboratories only for personal research with a few advanced students, and lecture demonstrations – not for general education. [67] The same was true for Berlin University's private laboratory of Johannes Müller, who pursued researches ranged from experimental physiology with the use of vivisectional techniques and chemical methods to cellular pathology, and from comparative anatomy to embryology, and whose personal laboratory was available only for exceptional students.

However, in another German state, the Grand Duchy of Baden, at the University of Heidelberg, as Arleen Tuchman has demonstrated, it was with Jacob Henle (1809-55) during the early 1840s that bench experience in the physiological laboratory became a necessary part of education for all medical students rather than the undertaking of a select few.[68] In Berlin University the first large-scale university-supported laboratory came in 1877 with the foundation of Emil du Bois-Reymond's new institute for physiology, in the ornate and imperial rhetoric of its founder, 'the regal lodgings for physiology, the queen of the natural sciences.'[69] As Turner has shown, in chemistry the same developments and the massive funding of the discipline came a decade earlier in

[66] On the university and pedagogical reforms, see Rocke, *The Quiet Revolution*, pp. 9-14, see also W. Coleman, "Prussian Pedagogy: Purkynje at Breslau, 1823-1839" in Coleman and Holmes, eds, *The Investigative Enterprise*, pp. 15-64

[67] Rocke, *The Quiet Revolution*, p. 28

[68] A. Tuchman, "From the Lecture to the Laboratory: the Institutionalization of Scientific Medicine at the University of Heidelberg" in Coleman and Holmes, eds, *The Investigative Enterprise*, pp. 65-99

[69] Cited in Lenoir "Science for the Clinic," in Coleman and Holmes, eds, *The Investigative Enterprise*, p. 139.

1865 upon the arrival to Berlin of August Wilhelm Hofmann (1818-92).[70]

The rise of experimental physiology in the nineteenth century was intimately linked to the development of the physico-chemical methods of investigation that began to dominate German physiology in the second quarter of the century. Although German physiology in the first decades of the nineteenth century had been strongly influenced by the romantic school of *Naturphilosophie* with its central notion of "vital forces," there began to appear at the same time the first works stressing the role of physics and chemistry in physiology. Edouard H. Weber in studies that employed an innovative physico-mathematical approach laid the ground for the interpretation of vital phenomena in strict physico-chemical terms.[71] The successes of physiological inquiry based on observation, dissections, and experimentation, a kind of 'animated anatomy' was best embodied in the works of Johannes Müller who was justly credited by his students not only as a 'reformer in physiology,' but also with the founding contributions to several research areas.[72]

An exacting new physical current in physiology flourished in Germany with Carl Ludwig and three of Müller's students, Hermann von Helmholtz, Emil H. du Bois-Reymond and Ernst von Brücke. In 1847 Helmholtz at the Berlin Physical Society read a paper entitled "Über die Erhaltung der Kraft" [On the Conservation of Energy]. Du Bois-Reymond in his letter to Ludwig wrote about this:" He has written a paper that simply cannot be praised enough: the conservation of energy. It is an exposition of the great principle of the constancy of energy and its application to various topics of natural

[70] S. Turner, "Justus Liebig versus Prussian Chemistry: Reflections on Early Institute-Building in Germany," *Historical Studies in the Physical Sciences* (1982) 13: 133-38; 144-47
[71] C. Ludwig *Rede zum Gedächtnis an Ernst Heinrich Weber*, Leipzig, 1878, pp. 9-10
[72] Emil du Bois-Reymond, "Gedächtnisrede auf Johannes Müller. Gehalten in der Leibniz-Sitzung der Akademie der Wissenschaften am 8. Juli 1858" in *Reden von Emil du Bois-Reymond*, in 2 vols. Leipzig, 1912, v. 1, pp. 200, 212, 263

science. … it is only because of Helmholtz's profound work that physics, having become a science, has received a goal."[73] A year later du Bois-Reymond published the first part of his famous *Untersuchungen über thierische Elektrizität,* in which he related his new methods on which all nineteenth-century physiologists were soon to rely.

Du Bois-Reymond's published works helped greatly in making his research methods readily available to others. Later Sechenov wrote about the significance of du Bois-Reymond's *Untersuchungen*: "One can judge the impact made by this book by the fact that from the end of the fifties up till now there is hardly any single physiologist in Germany who had not tried to study the phenomena which were touched upon in this work of du Bois-Reymond. Such was the impulse given by his researches."[74]

The instruments devised by du Bois-Reymond, Carl Ludwig, and Hermann von Helmholtz constituted a new generation of scientific instruments, which made it possible to trace and measure physical and chemical changes in isolated functioning organs. Even more important was the development and refinement of instrumentation that helped to transform experimental physiology into a new practical laboratory discipline.
Du Bois-Reymond's electrodes for conducting weak bioelectric currents and his multiplier for detecting and amplifying those currents became the key instruments of a standard physiological laboratory of the late fifties and early sixties, usually housed in a rather small room. These key instruments became immediately available from Sauerwald's workshop in Berlin.

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[73] Du Bois-Reymond to Ludwig, letter d. Berlin, 4 January 1848, in P. F. Cranefield, ed and S. Lichtner-Ayéd, transl, *Two Great Scientists of the Nineteenth Century Correspondence of Emil du Bois-Reymond and Carl Ludwig,* Baltimore, 1982, p. 6

[74] On E. du Bois-Reymond, *Untersuchungen über thierische Elektrizität.* 2 vols in 3, Berlin, 1848-1849, see I. M. Sechenov, "O dejatel'nosti Galvani i du Bois-Reymond v oblasti zhivotnogo elektrichestva" ["On Galvani and du Bois-Reymond's Researches in Animal Electricity"] in *Sobranie Sochinenii [Collected Works],* Moscow, 1908, v. 2, p. 452

Sechenov came to Berlin in 1856 and his acquaintance with Berlin University began with the courses of Magnus in physics and of Heinrich Rose in analytical chemistry. Sechenov's choice of subjects is not surprising providing his background in natural sciences during his studies at the Military Engineering School. For Sechenov both courses were essentially elementary, but he valued the excellent lecture-demonstrations:

> Magnus was considered a first-rate lecturer and an extremely skillful experimenter. Later in Heidelberg I heard about that from Helmholtz in his laboratory [Helmholtz succeeded Magnus in Berlin in 1871]. Magnus always tried to do the experiments in such a way that he could put into action an apparatus shown, or evoke the desired phenomenon, just by means of pulling a string or by some simple movement. His course was luxuriously provided with experiments done with such speed that they did not disturb the smoothness of the reading. Carbonic acid was changed in about a quarter of an hour into lumps of loose snow which were thrown among the listeners in the auditorium.[75]

Sechenov could scarcely imagine at that time that his first experimental success would be the improvement of Magnus's blood gas apparatus and method, and that Magnus's physicalistic thinking would be behind Sechenov's life-long interest in the state of carbon dioxide in the blood.

The main attraction for Sechenov at the University was Müller's laboratory. To his disappointment Müller did not admit physiology students, and gave the whole course of physiology in three months only in summer sessions:

> In my soul was still hidden the naïve habit, brought from Moscow, of thinking that each famous professor was necessarily a brilliant orator, and I expected to hear in this auditorium an absorbing talk full of wide generalizations, but instead I heard a purely business-like talk with a showing of drawings and preparations in alcohol. This was, however, the last year of

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[75] Sechenov, *Autobiographical Notes*, p. 69

Müller's glorious life, and at the lectures he appeared a tired, ill man. In all his movements and in his very speech certain nervousness was felt; he lectured quietly, not raising his voice, and only his eyes continued to burn with the indescribable brilliance which together with the famous name of the scholar became historical.[76]

A physiology course was given by Müller's disciple, du Bois-Reymond, then an extraordinary professor. According to Sechenov, du Bois-Reymond's lectures were not compulsory for medical students, and therefore he talked about whatever he wanted, and that was a course in electrophysiology. His lectures with many detours into innervation of the heart, intestines, and respiratory movements both by their content and their execution were fascinating. Du Bois Reymond's laboratory "consisted of a single room in which he himself worked, and the corridor adjacent to it with a window and a single plain table at the window," a place where Sechenov and one more student worked with the galvanometer. Later Sechenov noted that he was much indebted to the studies in the corridor for bench experience in electrophysiological methods and devices that gave him means to advance easily into the new area that so fascinated him. Learning the fine points of electrophysiological techniques proved crucial for Sechenov's later researches in nerve-muscle physiology at the St. Petersburg Medico-Surgical Academy.

Another principle place for the study of laboratory methods in Berlin was Felix Hoppe-Seyler's laboratory of medical chemistry in Virchow's *Pathologische Institut* where Sechenov started his research on the effect of alcohol on the human and animal organism, the topic of his doctoral thesis. Sechenov never before had a chemical practicum. Although in Moscow University chemistry was offered to medical students, they were not allowed into the laboratory. As a doctoral candidate Sechenov did not

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[76] *ibid.* pp. 69-70

even know how to handle a burner, chemical dishes, etc. He benefited from the studies at the private chemical laboratory of docent Franz Leopold Zonnenschein for two months before he could pass on to Virchow's institute.[77]

In Hoppe's "fine laboratory" Sechenov carried out experiments on the influence of alcohol poisoning on body temperature, and performed quantitative analysis of carbon dioxide exhaled by an intoxicated animal. Hoppe-Seyler, "a dear, able and lenient teacher who did not differentiate between Russian and German students," welcomed research proposals from his students, and if they proved to be reasonable and feasible, gave his encouragement and support.[78] Studying the influence of alcohol on nitrogen metabolism, Sechenov repeated on frogs Bernard's experiments on the action of various poisons on the nerves and muscles, and that became his first publication in Germany.[79]

Now we will look more closely at the most decisive influences that shaped scientific and pedagogical outlook of Botkin and Sechenov that proved important for the introduction of the laboratory and 'dualist professorial standard' of teaching and research to the Medico-Surgical Academy. We start with Botkin's studies with Virchow and Traube and then go on to discuss Sechenov's researches on blood gases in Ludwig's laboratory in Vienna.

[77] *ibid*, p. 67
[78] *ibid*, p. 68. On the Hoppe-Seyler research group see Fruton, *Contrasts in Scientific Style*, pp. 93-96
[79] I. Setchenow, "Einiges über die Vergiftung mit Schwefelcyankalium," *Arch. path. Anat. Physiol. und klin. Med.* (1858) 14: 356-70

3. 'Scientific Medicine' and European Clinics in the Mid-Nineteenth Century: Botkin's Experience

Sergei Petrovich Botkin (1832 –89), eleventh son of the wealthy Moscow tea merchant was educated at Einnes, one of Moscow's best private boarding school, well-known for its excellent instruction in classical and modern languages. But his passion at school was mathematics taught by Iu. K. Davydov, a young professor from Moscow University. However, Botkin was prevented from entering the mathematical faculty because of the limited access for students to any faculty except medical at that time. He had to choose medicine, which eventually became his real passion but he preserved an interest in exact sciences throughout his life.[80]

Botkin's decision to study in Germany after graduating from the medical faculty of Moscow University might have been influenced by N. I. Pirogov. Botkin had worked under Pirogov in the military hospital in Sevastopol by the end of the Crimean campaign just after graduation. He was prevented from specializing in surgery because of his weak vision, and decided to study abroad using his parents' funds. The first German University town Botkin visited on his way to Europe happened to be Königsberg. Here in the clinic of professor Girsch, Botkin heard about Rudolf Virchow and his new teaching on cellular pathology. After staying in Würzburg with Virchow for half a year, Botkin in 1856 followed "the best teacher in Germany" to Berlin.[81]

The new Pathological Institute headed by Virchow was one of the most attractive places in Berlin for medical researchers. Virchow's great interest at that time was further

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80 Belogolovyi, *Botkin*, p. 10
81 *ibid*, p. 21

refinement of his new theoretical formulation, cellular pathology,[82] and an institutional program in support of scientific medicine. Virchow promoted his theory through an integrative approach: normal histology and physiological chemistry were represented both by courses and the laboratory. Two of the first assistants at the new institute were Felix Hoppe-Seyler (1825-95), a chemist and histologist with clinical training in Vienna, and Friedrich von Recklingshausen (1833-1910), a clinician, skillful in devising laboratory methods and techniques in tissue pathology.

Botkin had already got training in microscopic techniques in the histology laboratory of Rudolf A. von Kölliker (1817-1905) in Würzburg during his studies with Virchow. Later Botkin in his recollections on those times remarked that the first lectures in cellular pathology had greatly disappointed him: "Virchow spoke about blood segments [blood cells] with thoroughness, typical for him, and about different morphological types. All these small details seemed to me boring and unnecessary." However, he soon realized the unique value of these small details in a new pathology that relied heavily on microscopic examinations. The young physician, who had got his first experience in the military hospital in Crimea, desperately fighting inflammation and suppuration in post-operative wounds, quickly saw the utility and importance of cellular pathology. Virchow's Institute intellectually and institutionally connected with the University and the Charité clinics became for Botkin as well as for numerous students and collaborators a place for investigation of both 'scientific' and clinical problems,

[82] R. Virchow, *Die Cellularpathologie in ihrer Begründung auf physiologische und pathologische Gewebelehre*, Berlin, 1858. On Virchow's institutional program at the end of the 1850s see R. Maulitz, "Rudolf Virchow, Julius Cohnheim and the Program of Pathology," *Bull. Hist. Med.* (1978) 52: 167-172; on reception of Virchow's theory in 1855-1865 in Russia see L. Shumeiko, *Die Rezeption der Zellularpathologie Rudolf Virchow in der Medizin Russlands und der Sowjetunion. Inaugural Dissertation*, Marburg, 2000, pp. 46-89

unifying science and medicine.

Botkin's choice of topic for the first research he carried out in Hoppe's laboratory of the Institute of Pathology is particular telling in this regard. It was a study of the effect of neutral salts on the circulation of red blood cells that could serve as an explanatory model for venous haemostasis. First he improved the method of application of salt solution to the walls of blood capillaries and got new results, which refuted the conventional explanation of that process in physico-chemical terms. He claimed that although the escape of the liquid part of the blood through the walls of vessel due to endosmosis occurred, the main cause of the haemostasis appeared in the loss of elasticity of the red blood cells: they became non-resilient and could not pass through the contracted capillary. His explanation was perfectly well in accordance with the dictum of a new pathology *omne cellula e cellula* and confirmed its rule: altered circumstances make altered cells.[83]

As Botkin had a strong inclination to practical medicine in preference to laboratory research alone, he spent much time in the clinic of Ludwig Traube (1818-76), which was situated close to the Pathological Institute in the Charité garden. The Charité clinic was one of the oldest clinics in Europe. Founded as a pest-house in the early eighteenth century, it became from 1727 a *Bürgerlazarett* for the army and was named the Charité by 'the Soldier King' Friedrich Wilhelm I (1688-1740). At the beginning of the nineteenth century with the foundation of the *Medizinisch-chirurgisches Friedrich-Wilhelms-Institut* it continued its traditional function from the times of the *Pepinière* (1795) in training army doctors. The Charité admitted medical students from Berlin

[83] S. Botkin,"Über die Wirkung der Salze auf die circulirenden rothen Blutkörperchen," and "Zur Frage von dem Stoffwechsel der Fette im thierischen Organismus" in *Virch. Arch.* (1858) 15 (v): 34-51

University as well as doctors and students from other lands attracted by the lectures of Lucas Schönlein (1793-1864) at the time one of the best clinicians in Germany who, in the words of Virchow, deserved his fame in pathological anatomy, which was the basis of his diagnosis. Schönlein was credited by his contemporaries for the introduction to German clinical medicine of the new French diagnostic methods of percussion and auscultation, and of more accurate pathologo-anatomical methods of microscopical and chemical examination of discharges, blood, and tissues of the diseased.[84] Pirogov who studied surgery at the Charité in the 1830s left an interesting and lively account of the Charité clinic and its leading surgeons Johann Nepomuk Rust (1775-1840), Carl Ferdinand Gräfe (1787-1840), and Johann Friedrich Dieffenbach (1792-1824). According to Pirogov, the 1830s was a period of a rapid transition to realism in German medicine: "the beginning of its ceremonial entry into the exact sciences."[85]

In the late 1850s, Ludwig Traube (1818-1876), the best of Schönlein's students, became the first civilian to be employed at the Charité. He soon became the most influential of the Berlin internists. His clinical approach and views had been formed during his post-graduate training in Vienna under Carl von Rokitanski (1804-78) and Josef Skoda (1805-81). His early interest in experimental research in the Breslau physiological laboratory of Johann Purkinje (1787-1869) during his student years, and his later keen interest in experimental pathology shaped his experimental thinking. In 1846, together with Reinhardt and Virchow he began to publish the periodical of the new school - the *Beiträge zur experimentellen Pathologie und Physiologie*, it ran for only one year and was superseded by Virchow's *Archiv für pathologische Anatomie und*

[84] J. Bleker, *Die Naturhistorische Schule, 1825-1845. Ein Beitrag zur Geschichte der klinischen Medizin in Deutschland*, Stuttgart, 1981
[85] Pirogov, *Questions of Life*, pp. 341-69

pathologische Physiologie und klinische Medizin founded in 1847. Influenced by their teacher Johannes Müller, Traube and Virchow demanded exactness and consistency not only in physiology but also in pathology. In his first published experimental work (1847) on the causes and nature of pathological changes in the lung parenchyma as the consequences of cutting the vagus nerves, Traube stated that only experiments combined with observation can make pathology what it should be, an exact science.[86] Virchow's ideal of clinical research was that practical medicine would become applied theoretical medicine, and theoretical medicine would become pathological physiology. His concept developed along the same lines as Carl Wunderlich's (1815-77) 'physiological medicine' that was intent on replacing anatomical research by physiological investigations. Wunderlich's *Archiv für physiologische Heilkunde* founded in 1842 gave its name to the new trend in German clinical medicine. Wunderlich stressed in his *Geschichte der Medizin* (1869) that pathology was only physiology of the diseased man, and it required the same means, methods and logic argumentation that were used in the science of the healthy man.[87] The new concept opposed what Wunderlich called the ontological personification of diseases in *Naturphilosophie*. In contrast to the French pathologico-anatomical doctrine of specificity, based on the purely descriptive method, physiological medicine began to be seen as strictly scientific: it relied on the new methods of investigation, graphic, microscopic and chemical.[88]

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[86] L. Traube, *Über Ursachen und Beschaffenheit derjenigen Veränderungen, welche das Lungenparenchym nach Durchschneidung der Nv. Vagi erleidet*, Berlin, 1846; see also, L. Traube, *Gesammelte Beiträge zur Pathologie und Physiologie*, 2 vols, Berlin, 1871, pp. v-vi

[87] C. Wunderlich, *Geschichte der Medicine*, Berlin, 1869, p. 13

[88] On the new clinical methods see V. Hess. "Klinische Experimentalstrategien im Kontext: Ludwig Traube, Carl August Wunderlich und das Fieberthermometer" in Ch. Meinel, ed. *Instrument – Experiment Historische Studien*, Berlin, 2000, pp. 316-24. On the German clinical school see Knut Faber. *Nosography in Modern Internal Medicine. with an introductory note by Rufus Cole*, New York, 1923, pp. 59-94

Traube, one of the first clinicians of a new stamp in Germany, strove to reconstruct clinical medicine along strictly physiological lines. In his work on the connection of heart and kidney diseases (1856) he developed the idea of variation in blood pressure, specifically in hypertension as a cause of the cardiac hypertrophy which had been observed in chronic nephritis. Traube's explanation of clinical phenomena in heart and kidney diseases was based on the results of experiments made by Ludwig and on his own careful observation and experimental research on animals with the improved Ludwig's haematodynamometer. Traube's synthesis of clinical and laboratory medicine found its best expression in his three volumes *Gesammelte Beiträge* with fine pictures of Ludwig's kymograph and its application and with the main chapters on experiments on animals, pathological-physiological-clinical investigations and studies in physico-clinical diagnostics.[89]

Traube's younger brother, Moritz (1826-1894), was also engaged in laboratory research. Forced by family obligations to maintain family's large wine business, he set up a private laboratory first in Breslau, where he used the opportunity to work at the physiological laboratory of Rudolf Heidenheim (1834-1897), and then in Berlin. Trained in medicine and chemistry under Liebig in Giessen Moritz investigated the biochemical processes of diabetes mellitus and distinguished two forms of the disease. His experimental studies extended over much of physiological chemistry and his original ideas and experiments proved of importance for general chemistry: oxygen-carrying ferments (1857) and semipermiable membranes (1867) are among his most interesting

[89] L. Traube, *Über den Zusammenhang von Herz-und Nierenkrankheiten*, Berlin, 1856, pp. 6-7. The only full-length biography of Traube to my knowledge is Hildegardt Stangier, *Ludwig Traube sein Leben und Werk*, Düsseldorf, 1935. On Traube's relationship with Virchow, see R. Virchow, "Errinerung an Ludwig Traube" in *Berl. Klin. Wschr.* (1876) 16: 200-9

discoveries.[90] Moritz's studies on the source of the energy for muscle contraction and on respiration were of particular interest and help for his brother's clinical research. Ludwig Traube re-examined the relationship of the blood gases to apnoea. In the course of his experiments he assumed that an excess of oxygen did not produce apnoea. He attributed dyspnoea to carbon dioxide excess and not lack of oxygen. Moritz Traube held a similar view on the problem in his earlier studies on the influence of carbon monoxide on the respiratory and circulation apparatus.[91]

Ludwig Traube's strong background in physiology and experimental methods combined with his clinical experience distinguished him among contemporary clinicians. According to Billroth, one of Traube's numerous students, his teaching clinic achieved such excellent results not just because of its name, but because of Traube's skill as a clinical teacher.[92] A Russian physician N. A. Belogolovyi, who studied together with Botkin under Traube, noted that Traube's extraordinary power of observation and keen clinical intuition helped him to grasp individual peculiarities in an ordinary clinical patient. His analysis of the patient's condition was even more interesting and instructive for the physicians who were more experienced in the nuances of diagnostics than for the students. His lectures always contained something new and

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[90] On Moritz Traube's researches in physiological chemistry see F. Lieben, *Geschichte der physiologischen Chemie*, repr. New York, 1970, pp. 235-41; in chemistry, see J. R. Partington, *A History of Chemistry*, 4 vols, London, 1964 (v. 4, p. 307); see also G. Rudolph, "M. Traube," in Ch. Gillispie, ed. *Dictionary of Scientific Biography*, New York, 1970, v. 13, pp. 451-3

[91] L. Traube, *Gesammelte Beiträge zur pathologie und Physiologie*, Berlin, 1871, v. I, pp. 288-9; M. Traube, "Über die Wirkungen des Kohlenoxyd-Gases auf den Respirations-und Circulations-Apparat," *Verhandl. Med. Gesell. zu Berlin*, 1867, p. 67f

[92] Th. Billroth, *Über das Lehren und Lernen der medizinischen Wissenschaften an d. Universitäten d. deutschen Nation*, Wien, 1876, pp. 102, 103. Theodor Billroth (1829-1894), a student of Rudolf Wagner, Müller, Schönlein, von Graefe, Bernard von Langenbeck had a quarter of a century been an active and successful teacher, investigator and a surgeon in three important universities: in Berlin, Zurich, and Vienna. Billroth was a close friend and admirer of Nikolai Pirogov, see Pirogov, *Questions of Life*, p. xxii-xxiii. On Billroth's Vienna period, see E. Lesky, *The Vienna Medical School of the 19th Century*, Baltimore, 1976, pp. 293-404

interesting that one could not find in any textbooks: a thought or observation, as well as fresh ideas or comments on the problems that were not yet solved. Needless to say, Belogolovyi continues, Botkin was not satisfied with lectures of any other notable clinicians in Vienna and Paris, to say nothing about old Schönlein in Berlin.[93]

In the fall of 1858 Botkin and Bekkers came to Vienna for the winter semester. Together with some other Russian students, they commissioned Sechenov to ask Carl Ludwig to give a series of lectures on the circulation of the blood and the innervation of the blood vessels in his laboratory at the Josephinum. According to Sechenov, Ludwig enjoyed lecturing. From the vivisection side, his lectures were splendidly arranged and were very successful. After the course the grateful participants invited the professor to a dinner arranged in his honor. Ludwig became more closely acquainted with both of Sechenov's friends. He was always very well disposed to Botkin and A. A. Krylova, his wife.[94] Botkin was impressed by Ludwig's mode of teaching: "Until now, Ludwig's lectures are the only ones I have liked. They surpass all my expectations for clarity and completeness. Ludwig is the best physiologist I have ever heard; his personality is nice, his simplicity and courtesy are astonishing."[95]

Nevertheless, Botkin was disappointed with his studies in Vienna: "I am displeased with Vienna ... you can not learn much here. It is a complete waste for a decent person to stay in Vienna more than three months."[96] His acquaintance with the traditionally famous Vienna medical instruction began with the clinic of professor

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[93] Belogolovyi, *Botkin*, pp. 23-4
[94] Sechenov, *Autobiographical Notes*, p. 85. Botkin's marriage with A. A. Krylov took place in Vienna in May 1859
[95] N. A Belogolovyi, *Vospominaniia [Memoirs]*, Moscow, 1897, p. 37
[96] Botkin to Belogolovyi, letter d. Vienna, 11 February 1859 in N. Sadovskaia, *Perepiska Botkina s Belogolovym*, p. 17

Johann von Oppolzer (1808-71), by then well known in Europe as a consulting physician and clinical teacher. However, Botkin liked neither the professor, nor his clinic: "Oppolzer is an excellent observer, a sharp diagnostician, and in general a kind of good practical physician...But how often he transgresses science: he cannot be considered a good clinician in a full sense of this word. Frequently he disregards chemistry, pathological anatomy, even physiology."[97] Botkin's pretty sharp criticism of Oppolzer accords well with Billroth's characterization of the representatives of the Prague and Vienna medical school: "In the case of Skoda and Oppolzer there was always a gap between medical art and modern physiology – between practice and theory – that was artificially and ineffectively bridged over. Appreciation of the big things in natural phenomena and in social life was almost entirely absent in Skoda and Oppolzer." Billroth's contrast of the Vienna school to 'the Berlin school' of Lucas Schönlein and Johannes Müller pointed to their extraordinary encyclopedic knowledge of the natural sciences and complete command of the physiology taught in those days.[98] Undoubtedly Botkin could learn excellent procedure for medical practice from Oppolzer. We can assume also that Botkin appreciated greatly his Berlin teachers, Traube, the most talented immediate pupil of Schönlein, and Virchow, Müller's student, and remained sincerely devoted to them throughout his life.

It is also fair to conclude that Botkin, an ardent proponent of Virchow's ideas, felt that 'the new revolutionary teaching' was not accepted in Vienna where pathological

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[97] *ibid*, p. 18

[98] Th. Billroth, *The Medical Sciences in the German Universities*, with W. Welch, "Introduction," New York, 1924, pp. 229-30. Oppolzer's most notable contribution was his *Klinische Vorlesungen über specielle Pathologie und Therapie*, Erlagen, 1866. A short and complimentary description of Oppolzer's theurapeutic activity and its impact on the development of Vienna medicine is given in Lesky, *The Vienna Medical School*, pp. 125-8: on Skoda see *ibid*, pp. 118-24

anatomy was ruled by Carl von Rokitanski, an authoritative macromorphopathologist. Rokitanski's 'new humoral pathology' was one of the targets of Virchow's criticism at the time when Virchow established the principles of cellular pathology based on microscopic and experimental method.[99] Interestingly, Botkin was extremely sensitive towards any criticism of Virchow's theory. Later on he wrote: "In those times Virchow was accessible to a few, his teaching was far from being common knowledge, as now, and his method of research and mode of thinking was open only to exceptional people."[100] Sechenov recalled that in Vienna he had an argument with Botkin about the role of the cellular principle in physiology and pathology. Sechenov could not accept Virchow's static and localistic anatomical idea of cellular pathophysiology. It took Ludwig's interference to reconcile the two friends in a letter to Sechenov.[101] The echo of this dispute can be traced in some of the statements in Sechenov's doctoral dissertation, for example: "The principles of cellular pathology are erroneous, because they are based on the assumption of the physiological independence of the cell, or at least of its domination over the surrounding environment. The theory of cellular pathology is an extreme expression of the purely anatomical trend in physiology. The only correct approach to pathology in our time is molecular [physico-chemical]."[102]

After Vienna, Botkin with his wife settled in Paris. His intention was to finish his doctoral dissertation *On the Absorption of Fat in the Intestine*. The experimental part had been already completed in Hoppe's laboratory in Berlin, and in Paris Botkin was

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[99] For Virchow's rejection of humoralism in his review of Rokitanski's *Handbuch der pathologischen Anatomie* see L. J. Rather, "Virchow's review of Rokitanski's *Handbuch* in the *Preussische Medizinal-Zeitung*," *Clio Med.* (1969) 4: 127-40; for Rokitanski's antilocalizationist views see Lesky, *The Vienna Medical School*, pp. 106-15

[100] Belogolovyi, *Vospominaniia*, p. 20

[101] Ludwig to Sechenov, letter d. Vienna, 14 May 1859, in M. N. Shaternikov, "I. M. Sechenov," in Sechenov, *Selected Works*, p. xii

[102] *Ibid*, p. xiii; see also Sechenov, *Autobiographical Notes*, p. 87

planning to get acquainted with Bernard's experimental research on physiology of digestion. Bernard had devised a series of experiments to test his theory that neutral fats were rendered absorbable through the action of the pancreas and its secretion. He had established as the special property of pancreatic juice in regard to fat that it had the chemical action of saponifying it, *i.e.*, breaking it down into fatty acid and glycerin.[103] In his thesis Botkin confirmed that neutral fats before the absorption through the walls of the intestine had undergone a process of saponification in order to be soluble in water. He demonstrated also that the impairment of the elastic epithelial layer of the intestine led to the impairment of the process of the absorption of fats. [104]

Botkin attended Bernard's course at the Collège de France. That year the course was devoted to *Liquids of the Organism.*[105] It might well be that Botkin was astonished by the number and the importance of the research works Bernard managed to complete and consolidate during the late 1850's, working in a dark, cold, damp laboratory of the Collège de France. Perhaps Bernard, a very skilful and able experimenter, inspired young Botkin, who seemed to be carried away with his own experiments at that time:

> I was not satisfied with reading, attending lectures and visiting clinics, so I arranged a small laboratory at home and started working like mad. I finished the work with the blood and got a lot of new and good results that helped to explain the facts I had obtained during my experimental work in Vienna. ... I managed to write a short work on diffusion of haematin and ferric pigment. Bernard became interested in this work and published it.[106]

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[103] Claude Bernard, *Mémoire sur le pancreas*, Paris, 1856. See, M. D. Grmek, *Le Legs de Claude Bernard*, Gèneve-Lyon, 1997, pp. 30-1; see also J. M. D. Olmsted & E. H. Olmsted, *Claude Bernard and the Experimental Method in Medicine*, London, 1952, pp. 53-5, and F. L. Holmes, *Claude Bernard and Animal Chemistry: the Emergence of a Scientist*, Cambridge, MA, 1974, pp. 1-32
[104] S. Botkin, *O vsasyvanii zhira v kishkakh. Dissertatsiia* in *Voenno-meditsinskii zhurnal [Military-Medical Journal]*, St. Petersburg, 1860
[105] Claude Bernard, *Leçons sur les propriétés physiologiques et les alterations pathologiques des liquids de l'organisme*, Paris, 1859
[106] Botkin to Belogolovyi, letter d. Paris, March 1859, cited in Sadovskaia, *Perepiska Botkina s Belogolovym*, p. 23

By that time, according to Sechenov, experiments with the action of curare on nerves and muscles of Bernard and Kölliker, "had caused a lot of excitement, and experiments with the influence of various poisons on the muscles and the nervous system were very much in vogue." Bernard, who was fascinated by curare as "an instrument, which dissociates and analyses the most delicate phenomena of the living organism," had carried out many experiments on dosage and the progressive action of curare on the nervous system that revealed the realities of death by curare.[107] Botkin was also captivated by the experiments with curare; he wrote to Belogolovyi:

> ...I started with frogs, and sitting at the experiments I came across a new curare, atropine sulphate; I had to repeat all the experiments which had been done with curare before. I was so fascinated by newness of the methods (I had not applied them in my work), the successful results and the instructive character of the work that I was sitting with the frogs from morning till night; I would have sat with my experiments longer if my wife had not turned me out of my home laboratory. She had no patience with me during my madness, as she called it... Anyway, owing to this work I learnt much.[108]

Botkin's interest in the traditionally famous Paris school of medicine was no less than in Bernard's experimental work. One of the leaders of clinical medicine in France at that time was Armand Trousseau (1801-67). A disciple and admirer of the Parisian clinician Pierre Bretonneau (1771-1862) and his doctrine on specific inflammations and specific diseases, Trousseau continued his studies on diphtheria, croup, and typhoid fever in terms of the description of their various forms and stages and included them in his eloquent lectures. Contrary to Wunderlich and his group, Trousseau stressed the specific nature of disease, which, he held, dominated all pathology, all therapy, and all

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[107] Claude Bernard, *Introduction à l'étude de la médicine expérimentale*, Paris, 1865, H. Green, transl., New York, 1958, p. 88.
[108] Belogolovyi, *Botkin*, p. 37

medical science. "The natural history of diseases resembles that of animals or plants; it deals, in the same way, with specific properties which separate the species."

Not surprisingly, Trousseau was also an antagonist of cellular pathology. He wrote in this connection: "It [cellular theory] regards the living organism as a small world consisting of heterogeneous and independent elements, therefore it rejects general treatment that cannot affect the elements which are dissimilar and to some extent counteracting one another. It forgets about a human being and thinks only about the cells and in that way disappears in a huge number of extremely small values."[109]

Trousseau opposed the intrusion of chemical methods into the domain of clinical medicine: he lamented in his lectures that with the emergence in medicine of new sciences, therapeutics had become neglected, and no one thought about how to relieve sufferings of patients or how to cure them. Botkin might sympathize with some of Trouseau's views, in particular, concerning the importance of observation at the bedside. He realized that there was a gap between the advances of pathological anatomy and diagnostics that had become 'exact sciences,' and therapeutics which still remained an 'art.' However, he did not share the opinion of 'therapeutic nihilism' with its dictum that scientifically educated physicians attached no importance to the art of healing. Botkin felt that the intuition of the physician was still a significant factor especially in the cases when 'exact knowledge' was still powerless. On the other hand, he believed that "a clinician should apply to the patient all means available in modern scientific medicine."[110]

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[109] Cited in K. Faber, *Nosography in Modern Internal Medicine*, New York, 1923, p. 92; on Bretoneau's doctrine of specificity see *ibid*, pp. 44-5

[110] Belogolovyi, *Vospominaniia*, p. 46

Botkin, who attended Trousseau's lectures and his clinic, was disappointed with Trousseau's unwillingness to embrace the new ideas:

> Trousseau holds his clinic in a rather routine way; being satisfied with hospital diagnostics [that is, based only on practical observations but not on experimental data], he prescribes an absolutely empirical treatment... Trousseau is considered here one of the best therapeutists; his lecture halls are always full. I think one of the main reasons of his success is that his oratory always wins over the French.

He was also disappointed and even astonished by the state of some Parisian clinics:

> In Codemont's urology clinic microscopic investigations were disregarded: in two cases of kidney stones and resulting bladder disease, despite positive evidence in the urine, the diagnosis and treatment were incorrect. The blunder was made before my eyes by the best medical authorities of the city. ... In the infant's clinic the mortality is severe. That partly depends on poor care, badly heated wards, etc. There is an epidemic of croup here, and nearly all children die, either with cut or whole throat.[111]

Botkin was convinced that "a physician must be scientifically educated. The clinic should not be entrusted to even a very good practical physician. The diagnoses of such a physician would be always of a hospital character and his treatment without experimental basis, would inevitably be of an empirical kind."[112] His criticism of the clinical thinking of Vienna and Paris as not being oriented towards a radically new conception in pathology and towards experimental innovation in physiology reflected his eagerness to embrace the entire research program available in Virchow's institute and in Traube's clinic closely associated with it. The systematized and well-planned training and research in physiological chemistry in Hopper-Seyler's laboratory at the Pathological Institute embodied for Botkin an important link between science and the

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[111] Botkin to Belogolovyi, letter d. Paris, October 1859 in Sadovskaia, *Perepiska*, p. 24. On Trousseau and the debate on tracheotomy versus intubation in the French Academy of Medicine, see G. Weisz, *The Medical Mandarins. The French Academy of Medicine in the Nineteenth and Early Twentieth Centuries*, Oxford- New York, 1995, pp. 169-73

[112] Belogolovyi, *Vospominaniia*, p. 48

clinic: chemical analysis of the bodily fluids as a new diagnostic tool rendered the art of healing quantitative thus transforming it into exact science.

Botkin's images of Paris, Vienna and Berlin medicine confirm in their own way the historical assumption that, after mid-nineteenth century, Germany became dominant because of the ability to integrate clinical and laboratory medicine.[113] But these images also reflect the intellectual vitality and excitement of the Paris school as it continued to attract Russian medical intellectuals during the age of the growing ascendancy of German medicine. Paris and Vienna, with their rich medical tradition, gave a final touch to the formation of the research and clinical experience of Botkin who would soon initiate the reorientation of Russian medicine towards a 'science for the clinic' imperative.

4. A Viennese Prelude to the Rise of Experimental Physiology in St. Petersburg.

Sechenov's tour abroad began in Berlin and then continued in Leipzig, at the University, where he studied for some time with Otto Funke (1828-1879), who headed the chemical section of the physiological institute of Ernst Heinrich Weber (1895-1878). But the crucial point in Sechenov's career came in 1858, when he moved from Leipzig to Vienna to Carl Ludwig laboratory. Ludwig's approach to physiological problems was decisive in formation of Sechenov's later scientific style and life-long interest in the

[113] The literature on the Paris school of medicine is extensive. I draw on the classical E. Ackerknecht, *Medicine at the Paris Hospital, 1794-1848*, Baltimore, 1967; on French school of experimental science I base myself on J. Lesch, *Science and Medicine in France. The Emergence of Experimental Physiology, 1790-1855*, Cambridge, Mass., 1984; I also found useful the work on the historical significance of the Paris school that emphasizes a social development of a new kind of scientific community – Weisz, *The Medical Mandarins*, as well as his recent essay review "Reconstructing Paris Medicine," in *Bull. Hist. Med.* (2000) 75: 105-19

study of blood gases. Sechenov's *Autobiographical Notes* contains many warm and fascinating reminiscences of Ludwig, the "incomparable teacher:"

> Ludwig was famous at that time for his skill in vivisection as well as important work on circulation of the blood, and later became an international teacher of physiology for almost all parts of the world. To occupy such a position it was not enough to have talent (Helmholtz, while he was a physiologist, and du Bois-Reymond, in all his long activity, had few laboratory students). Besides talent and variety of knowledge, certain traits of character were still necessary in a teacher, and also methods of teaching which make a period in the laboratory not only a useful but a pleasant business for a student. Invariably friendly and cheerful both in moments of rest and at work, he took a direct part in everything which was undertaken according to his instructions. He usually worked not by himself, but together with his students, carrying out with his own hands for them the hardest parts of the problem and only now and then printing his own name beside the student's name who had worked more than half with the teacher's hands.[114]

A series of Ludwig's letters to Sechenov that spans more than thirty years reveals a deep and close friendship between these two men, who are still remembered as the towering figures of nineteenth century German and Russian experimental physiology.[115] Whenever in critical moments of his not simple professional and scientific career, Sechenov always found consolation and comfort with Ludwig, whose good will "did not cease, right up to his death, manifesting itself at all the little turns in my life with warm, compassionate letters."[116] In his letters Ludwig used to report sentimentally on the achievements of other of his Russian students who were particularly welcomed to work in his laboratory. Ludwig's letters also offer glimpses of

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[114] Sechenov, *Autobiographical Notes*, p. 82

[115] Unfortunately Sechenov's letters to Ludwig are not preserved. Probably they were lost like much of the archival material of Leipzig University during the bombardment of Leipzig in 1945. Ludwig's letters to Sechenov are located in the Archive of the Russian Academy of Sciences in Moscow (fond 605, opis' 2/1752). They are published in Shaternikov, "I. M. Sechenov," in Sechenov, *Selected Works*, Shaternikov, ed. and also in H. Schröer, *Carl Ludwig, Begründer der messenden Experimentalphysiologie 1816-1895*, Stuttgart, 1967, pp. 248-62

[116] Sechenov, *Autobiographical Notes*, p. 87

academic milieu including interesting remarks on close associates, du Bois-Reymond, Brücke, Helmholtz, Bunsen and Ostwald, and provide invaluable source of his views on scientific and institutional matters.

Sechenov stayed in Vienna more then a year. Most of his time he spent in Ludwig's laboratory: he continued the experimental part for his thesis, and sometimes assisted Ludwig in his experiments on saliva secretion registered by the kymograph. These experiments were interesting and instructive as well as entertaining: Ludwig loved to chatter at his work. He liked to ask Sechenov about Russia. The German professor was interested in Lermontov,[117] whose works he knew in translation, and Sechenov recited for him Lermontov's poem *The Gifts of Terek*, which is famous for its fascinating descriptions of wild Caucasian nature. He was frequently received by Ludwig's family, which, in Sechenov's words, "consisted of his wife, a very modest, taciturn woman, and a daughter of fifteen." Walks about the closest environs, open air Strauss concerts in the *Volksgarten*, and trips by steamboat along the Danube were Sechenov's only amusements.[118]

Ludwig taught at the Josephinum - the *Kaiserlich-königliche chirurgische Militär-Akademie*. According to Sechenov, Ludwig was not able

> to display his qualities widely. His laboratory consisted of three rooms: a very small library (his study), an auditorium for about fifty people, and the so-called workshop where a

[117] Mikhail Iur'evich Lermontov (1814-1841) Russia's famous romantic poet and novelist, of old aristocratic provenance, served as an officer in the Imperial guards in St. Petersburg. In 1837 Lermontov was exiled to the army in the Caucasus for his poem "Na smert' poeta" ["On the Death of a Poet"] dedicated to A. S. Pushkin (1799-1837) who was killed on a duel by a French officer of the St. Petersburg Imperial guards. Four years later, Lermontov's duel with one of the officers of his regimen in the Caucasus was fatal. With their extremes of mood, their aesthetic and moral individualism and above all, with their Caucasian settings, his works were a magnet for the Russian composers of the second half of the nineteenth century. Lermontov is also famous for his translations from Lord Byron (1788-1824), Friedrich Schiller (1759-1805), and Wolfgang Goethe (1749-1832).

[118] *Autobiographical Notes*, pp. 83-4

laboratory attendant worked. The Josephinum was a closed institution; the laboratory according to the regulations was not intended for the students practical studies, and the professor did not receive a fee from the students. For all these reasons during the whole year of my stay only two of us worked there in the laboratory.[119]

Lesky points out that the research facilities at the Josephinum were limited compared with Brücke's Physiological Institute at Vienna University or with those which Ludwig was to create for himself later in the Leipzig Physiological Institute.[120] However, Ludwig seemed to be satisfied with the conditions he had been offered at the Josephinum. He wrote to du Bois-Reymond: "I have been given a friendly welcome in Vienna and have hopes of being able to set up a fine and useful institute; they are willing to make available as much money as I desire, and so to start with, I shall shortly be installing the equipment I need for my lectures." In the same letter he asked his friend to purchase for him a multiplier and a sledge inductorium from Sauerwald.[121] As Ludwig served in a military institution he was supposed to wear the elegant uniform of an Austrian army surgeon. He mentioned about it with slight irony in his letter to du Bois-Reymond: "The first course starts the day after tomorrow, for the first time in shining armor: golden collar, white pantaloons, and golden hilt of sword. Can you imagine?"[122]

Although the Josephinum's administration was extremely interested in hiring one of the best German experimental physiologists, the members of the Committee were cautious enough to prepare a secret service report on Ludwig, which contains interesting remarks on his personality and appearance. Ludwig seemed to be aware of the

[119] *Idem*, p. 82
[120] Lesky, *The Vienna Medical School*, p. 238; see also H. Wiklicky, *Das Josephinum: Biographie eines Hauses. Die medizinisch-chirurgische Josephs-Akademie seit 1785. Das Institut für Geschichte der Medizin seit 1920*, Vienna, 1985
[121] Ludwig to du Bois-Reymond, letter d. Vienna, 3 September 1855, in Cranefield, ed., *Two Great Scientists*, p. 88
[122] Ludwig to du Bois-Reymond, letter d. Vienna, 7 October 1855, in *ibid*, p. 91

complexity of the situation: he informed du Bois-Reymond that, "when the Viennese commenced their negotiations they imposed the strictest secrecy on me because here, as in your parts, the nomination was opposed by some serious resistance."[123] In his letter of acceptance of the chair of physiology and zoology at the Josephs Academy Ludwig wrote: "Extensive experience, which has shown to me not only the attractive, but also the dismal sides of universities makes it appear very likely to me that your Josephs Academy will offer the conditions under which a professor can teach efficiently and pursue his own academic development without disturbance." Ludwig's requirements (very high salary of 2600 florins, pension, etc.) were fulfilled by the order of Emperor Franz-Joseph.[124] We will return to the Josephinum in the following chapter in connection with the reformation of the St. Petersburg Medico-Surgical Academy and the crucial changes in military-medical education after the Crimean War.

Before analyzing Sechenov's blood gas research in Ludwig's laboratory, it is useful to put his research objectives into perspective and to discuss the major points in respiratory physiology of the time. Historians of physiological chemistry rightly point to the importance of the studies of Gustav Magnus in focusing attention of scientists, engaged in respiratory researches on the problem of gaseous exchange taking place in the blood and in the lungs. Since Lavoisier's theory of respiratory combustion had been undermined by the data collected over the first third of the nineteenth century, common consensus on the gaseous exchange during respiratory processes was absent. It was only

[123] Ludwig to du Bois-Reymond, letter d. Vienna, 3 Sept. 1855, in *ibid*, p. 87

[124] These materials are preserved in the War Records Office in Vienna, and published by P. G. Spieckermann, "Physiology with Cool Obsession: Carl Ludwig: his Time in Vienna and his Contribution to Isolated Organ Methodology," in *Pflügers Arch. Eur. J. Physiol.* (1996) 432: 33-41(34)

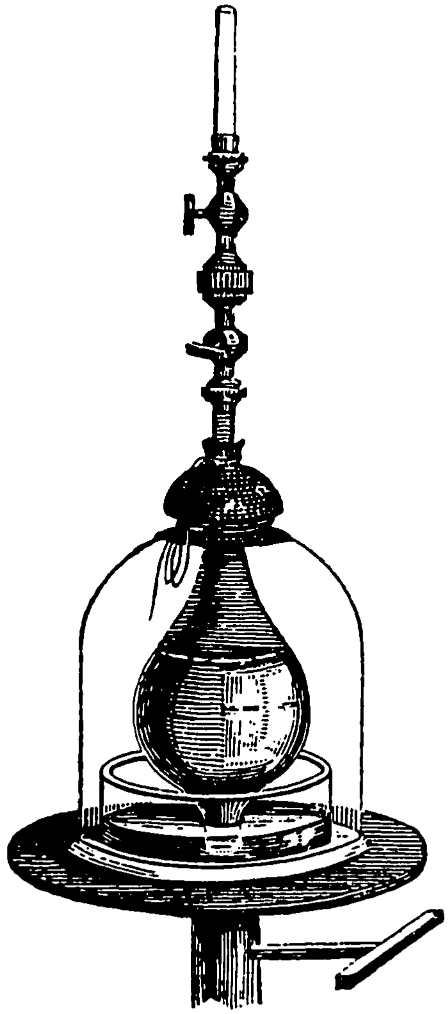

Figure 1. The apparatus of Gustav H. Magnus for determination of blood gasses. From G. H. Magnus, "Über die im Blute enthaltenen Gase, Sauerstoff, Stickstoff und Kohlensäure" (1837) p. 594. For description see p. 68 opposite

after the presence of free or at least recoverable oxygen in the blood had been confirmed, that the free exchange theory rose to the forefront of scientific interest.[125]

Jons Jakob Berzelius was the first to focus the interests of physiologists and chemists on the chemical processes and chemical composition of the animal body. He was interested in the problem of possible existence of gases in the blood. His student and collaborator Magnus took up the problem in 1837: in a letter to Berzelius he mentioned that he had investigated the problem of the possibility of extracting gases from the blood with the help of the air pump alone, without the addition of the acetic acid to blood.[126] The same year Magnus published the results of his experiments with blood gases. Not only did these experiments reveal the existence of carbon dioxide, nitrogen and oxygen in both venous and arterial blood, but they also suggested a method of the extraction of gases dissolved in the blood. Magnus's apparatus, a 'shortened barometer' which produced a Torricellian vacuum [127] over the blood sample, consisted of an inverted 'separator funnel' full of mercury into which the blood sample was introduced from below before closing the stopcock. The level of the mercury was then lowered by evacuating the air from the enclosing bell jar with an air pump. The liberated gas was

[125] P. Astrup and J. Severinghaus, *The History of Blood Gases, Acids and Bases*, Copenhagen, 1986, pp. 84-85; Ch. A. Culotta, *A History of Respiratory Theory: Lavoisier to Paul Bert, 1777-1880*, Doctoral Diss., University of Wisconsin, pp. 89-92, 138-41; F. Lieben, *Geschichte der physiologischen Chemie*, New York, 1970, pp. 266-7

[126] Magnus to Berzelius, letter d. Berlin, April 1837, cited in E. Hjelt, ed., *Aus Jacob Berzelius' und Gustav Magnus's Briefwechsel in den Jahren 1828-1847*, Braunschweig, 1900. pp. 122-3

[127] Evangelista Torricelli (1608-1647) one of the outstanding natural scientists of the time, studied under Galileo Galilei (1564-1642) and after Galileo's death took his positions of mathematician and philosopher to the Grand Duke of Tuscany. His experiments with liquids heavier than water (such as honey and mercury) led to the discovery of the principle of the barometer, for which he is probably most famous. Torricelli stated that it was the air pressure that sustained the mercury column when the glass tube, after being filled with mercury, was inverted and placed vertically in a bowl full of mercury with its open end at the bottom. See, V. Katz, *History of Mathematics*, Reading, Mass, 1998, pp. 478-80; W. Knowles Middleton, *The History of the Barometer*, Baltimore, 1964, Ch. 2

analyzed in Volta's eudiometer according to the well-established practice.[128] In his later investigations of blood gases published in 1845, Magnus stressed the necessity to determine the absorption coefficients for gases dissolved in blood. He assumed that the quantities of gases in the blood depended on their absorption coefficients and on their partial pressures, following Henry's and Dalton's laws of absorption.[129] It was in essence an explanation of the mechanism of the blood gases exchange in strictly physical terms. Another known physical law of diffusion was applied to explain the passage of oxygen and carbon dioxide through the lungs by the notable physiologists Gabriel G. Valentin (1810-83) and Karl von Vierord (1818-84).[130]

However, the leading chemists of the time, Berzelius and Justus Liebig (1803-1873), demonstrated that the quantities of oxygen and carbon dioxide present in the blood were too large to be explained by physical laws alone. The experimental data

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[128] H. G. Magnus, "Über die im Blute enthaltenen Gase, Sauerstoff, Stickstoff und Kohlensäure," *Ann. d. Phys. u. Chem.* (1837) 10: 583-606 (594). Eudiometer (Gr. *eudia* fair, clear weather, and *meter*) invented by Alessandro Volta (1745-1827) for exploding gaseous mixtures by an electric spark, and the characterization of methane (marsh gas), an instrument finely graduated and calibrated tube for the volumetric measurements and analysis of gases, formerly used to determine the purity of the air. See Partington, *A History of Chemistry*, v. 4, p. 6. On the emergence and fate of the eudiometric technology in the context of medical and managerial ambitions of physicians and natural philosophers of the late Enlightenment, see S. Schaffer, "Measuring Virtue: Eudiometry, Enlightenment and Pneumatic Medicine," in A. Cunningham and R. French, eds, *The Medical Enlightenment of the Eighteenth Century*, Cambridge, 1990; see also Trevor H. Levere, "Measuring Gases and Measuring Goodness," in Holmes and Levere, eds, *Instruments and Experimentation in the History of Chemistry*, pp. 105-36

[129] H. G. Magnus, "Über das Absorptionsvermögen des Blutes für Sauerstoff, " *Ann. d. Phys. u. Chem.* (1845) 66: 195-196. John Dalton (1766-1844) proved in 1801 that the absorption in liquids of the separate gases in a mixture is dependent on temperature and partial pressure. Dalton's close friend, William Henry (1774-1836), who held an MD degree from Edinburgh, showed in 1803 that the amount of a gas dissolved in a liquid is proportional to its pressure: $p^2 = KN^2$ where p is partial pressure, N is mole part in a solvent, K is Henry's constant. See *Khimicheskii entsiklopedicheskii slovar' [Chemical Encyclopedic Dictionary]*, Moscow, 1990, p. 158. The formulation of both laws led to the definition of absorption coefficients for gases dissolved by liquids, a prerequisite for the development of a rational respiratory physiology of the second half of the nineteenth century.

[130] K. Vierordt, *Physiologie des Athmens mit besonderer Rücksicht auf die Ausscheidung der Kohlensäure*, Karlsruhe, 1845, pp. 222-224; G. Valentin, *Lehrbuch der Physiologie des Menschen*, in 2 vols, Braunschweig, 1844, v.1, pp. 518-26. On other physicalist theories in German physiology see P. Cranefield, "The Organic Physics of 1847 and the Biophysics of Today," *J. Hist. Med. a. Allied Sci.* (1957) 12: 407-423; E. Mendelson, "Physical Models and Physiological Concepts: Explanations in Nineteenth-Century Biology," *Brit. J. Hist. Sci.* (1965) 2: 201-219; Culotta, *History of Respiratory Theory*, pp. 174-6

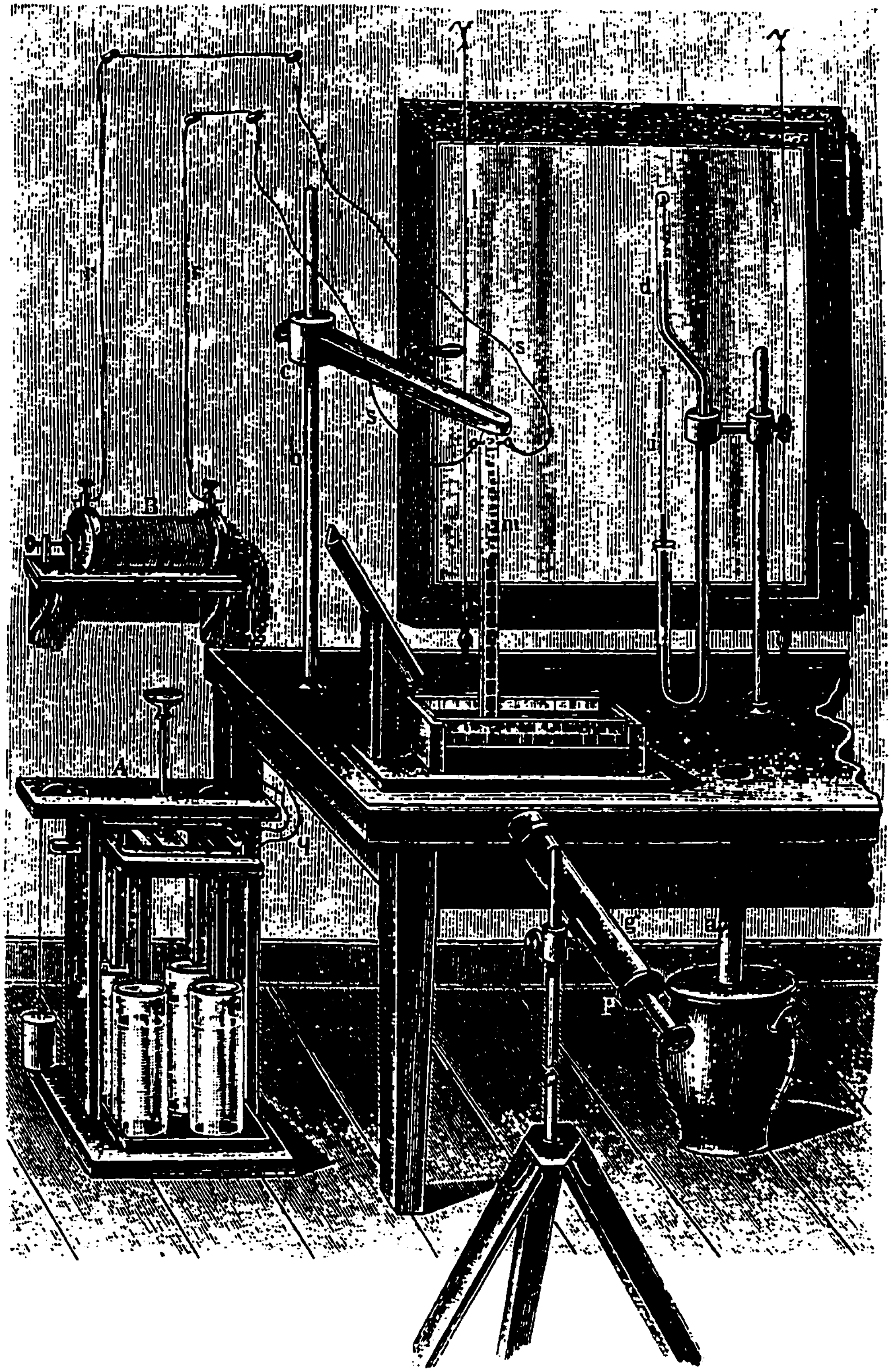

Figure 2. The apparatus of Robert W. Bunsen for gas analysis. From R. W. Bunsen, *Gasometrische Methoden* (1857) p. 25. For description see p. 70 opposite

showed that the formation of bicarbonate salts was the binding agent for carbon dioxide in the serum, and it was demonstrated that the red blood corpuscles had a chemical affinity for oxygen. Experimental findings suggested also that the gases of the blood were in a bound state.[131] Thus a chemical approach to respiratory theories began gaining ascendancy over the strict application of physical laws.

Robert Bunsen (1811-1899), famous nowadays for his gas burner used in every laboratory, devised the methods and apparatus for gas analysis that also proved decisive in the development of the techniques for analysis and extraction of blood gases; his methods and apparatus permitted a quantitative precision that could not be reached by Magnus' method. Bunsen's methods of gas analysis were basically physical: he applied chemical tests if they could yield accurate quantitative results. The calculation of the absorption coefficients for nitrogen, hydrogen, carbon dioxide, oxygen, pure water involved determination of the physical conditions such as temperature, pressure and the volume of gas absorbed. The standard absorption coefficients and mathematical formulas derived by Bunsen could be applied to calculate any of these parameters with accuracy. His method, based on Dalton' assumption that the partial pressure of a gas controls its absorption by a liquid, was so precise that it became widely used by all major chemists as a quantitative test for the presence of gases in liquids.

The methods in gas analysis, using the strait-tube eudiometer over mercury, and solid absorbents in the form of small spheres on the ends of platinum wires, were described in Bunsen's *Gasometrische Methoden* of 1857. Bunsen eliminated a single gas from a mixture of gases in a chemical reaction, and, by measuring the volume,

[131] Sechenov, *Autobiographical Notes*, p. 138; see also Lieben, *Geschichte der physiologischen Chemie*, pp. 268-9, and Culotta, *History of Respiratory Theory*, pp. 176-8

temperature and pressure before and afterwards, was able to determine the quantity of the eliminated gas. Dividing his book into six parts, Bunsen presented methods of collecting, preserving, and measuring gases, techniques of eudiometric analysis, new processes for determining the specific gravities of gases, and the results of his investigations on the absorption of gases in water and alcohol using the absorptiometer he himself had devised. [132]

There were two major implications of Bunsen's laws of gaseous absorption for the development of the techniques of blood gas extraction: the variability of the absorption coefficients with temperature: the most successful methods, that of Lothar Meyer (1830-1895) and Sechenov, included means of maintaining the temperature of the blood sample to obtain the most possible accurate results. The second implication was the importance of the relationship between partial pressure and the absorption of gases. Even more significant for the blood gas research done by Meyer and then taken up by Sechenov in 1857 were Bunsen's standard of the absorptive coefficients of water and the method of its determination, which ultimately led to establishing an analog model in which blood reproduced certain relevant features of water.

Bunsen stressed the importance of his method of analysis for the research on the absorption of gases by the blood. [133] His student Lothar Meyer (1830-1895) undertook that task. As Cranefield has pointed out, the most striking example of the influence on the development of nineteenth century science of the friendship between Ludwig and

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[132] For Bunsen's method and apparatus, see R. Bunsen, *Gasometrische Methoden*, Braunschweig, 1857; R. Bunsen, *Gasometry*, H. Roscoe, transl, London, 1857, pp. 128; 138-40. For a detailed account of Bunsen's laboratory and his *Vorlesung über allgemeine Experimentalchemie* see T. Curtius and J. Rissom, *Geschichte des chemischen Universitäts-Laboratoriums zu Heidelberg seit der Gründung durch Bunsen*, Heidelberg, 1908, pp. 4-26

[133] R. Bunsen, "Über das Gesetz der Gasabsorption," *Ann. der Chemie und Pharm.* (1855) 93: 47-54 (50) On Meyer's research in Bunsen's laboratory, see H. Roscoe, "Robert Wilhelm Bunsen," in B. Z. Jones, ed., *The Golden Age of Science*, New York, 1966, p. 394

Bunsen was Lothar Meyer's turn from a physiologist into a chemist.[134] Ludwig and Bunsen became friends in Marburg where both were professors from 1839-1849. The British physiologist John Burdon-Sanderson pointed out that it was Bunsen from whom Ludwig "derived that training in exact sciences which was to be of such inestimable value to him afterwards."[135]

Meyer studied medicine first in Zürich, when Ludwig held the chair of physiology there, and then in Würzburg where Virchow was lecturing on pathology. Meyer's interest in the problems of physiological chemistry, encouraged by his physiology teacher Ludwig, soon led him to Bunsen's laboratory in Heidelberg, where Meyer spent two years from 1854 to 1856. There, inspired by Bunsen's research on gas analysis, Meyer performed important investigations on blood gases, which he dedicated to Ludwig.[136]

Meyer challenged Magnus's method for determining gases of the blood using a different principle that involved boiling in a vacuum as suggested by Bunsen. It enabled Meyer to demonstrate in 1856 that oxygen absorption by the blood had no dependence on a fairly wide range of relatively high partial pressures. It meant that apart from the physical binding of oxygen there must be chemical binding in the blood, but that the chemical binding was relatively loose or weak. Hence the oxygen could be expelled from the blood at low pressures or as a result of shaking the blood with other gases. Meyer suggested two methods of determining blood gases. The first one, 'Auskochung'

[134] P. Cranefield, "Robert Bunsen, Carl Ludwig and Scientific Physiology," *Research in Physiology: a liber memoralis in honour of Prof. Chandler McCuskey Brooks, F. Kao, K. Koizumi and M. Vassale, eds,* Bologna, 1971, pp. 743-8 (746)
[135] J. Burdon-Sanderson, "Karl Ludwig," in *The Golden Age of Science,* Jones, ed., pp. 409-10
[136] L. Meyer, *Die Gase des Blutes,* Göttingen, 1857. That work was accepted by the Würzburg Faculty of Medicine as his doctoral dissertation.

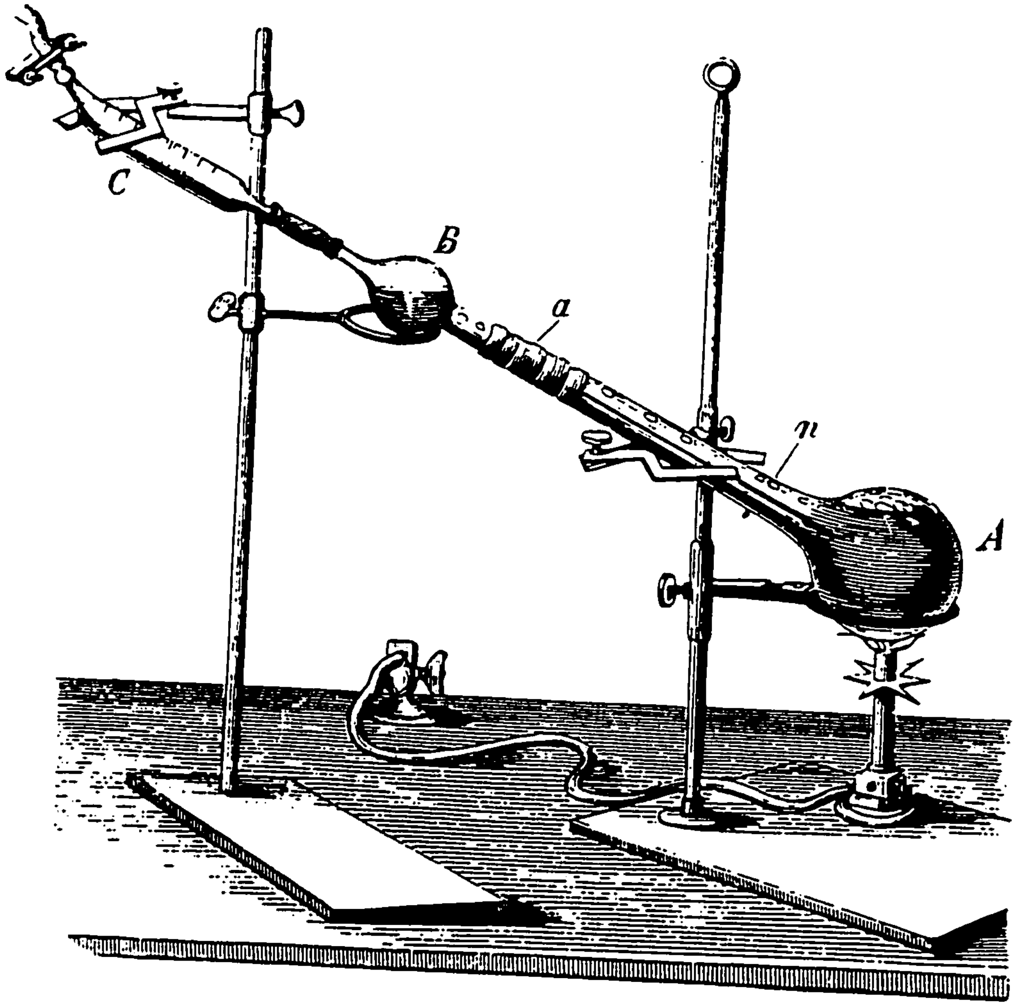

Figure 3. The apparatus of Lothar Meyer for measuring blood gases. From L. Meyer, *Die Gases des Blutes* (1857) Plate II. For description see p. 73 opposite

(boiling out), eliminated the major defect of Magnus's method, which required the prolonged contact with mercury (up to six hours). The 'Auskochung' method reduced foaming of the blood in the vacuum so that it was possible to extract more carbon dioxide. Meyer's second method involved the evaluation of the effects of pressure on absorption of gases by the blood using Bunsen's formulas.[137]

Meyer showed special skill in devising apparatus. Although his apparatus was a modification of Bunsen's absorption apparatus, his version was better adapted to the analysis and gas extraction procedure from the blood. The blood sample was transferred to the bottom flask *A*, which contained boiled out distilled water. The content of the flask was brought to the boil so that the air above was expelled to the flask *B*, which initially also contained distilled water, and then to tube *C* where it collected. It was possible to regulate the pressure within the system and there was no prolonged contact of the blood with mercury or water. However, Meyer clearly saw practical impossibility of getting results of high accuracy, as he could not control the temperature of the apparatus.[138] Therefore, according to Sechenov, Meyer's results on the content of oxygen in the blood were fairly accurate, but his estimates of carbon dioxide were not efficient.[139]

The imperfections of Meyer's first method were improved by Emil Fernet, a professor at École politechnique, who eliminated the condensation and maintained a more constant temperature of the apparatus. In his work published the same year as Meyer's *Die Gase des Blutes* Fernet gave a lengthy review of the research that had been

[137] Meyer, *Die Gase des Blutes*, pp. 55-6
[138] *ibid*, p. 88
[139] On Meyer's method and apparatus see I. Setchenow, "Beiträge zur Pneumatologie des Blutes," *Sitzungsber. Akad. Wiss., Wien, math.-naturwiss. Kl.* (1859) 36 (2): 293-319, citation from the reprint in Sechenov, *Selected Works*, pp. 3-24 (p. 4)

done on the problem.[140] The importance of Meyer's method and its improved modification by Fernet was in providing experimental evidence that the gases associated with respiration were not simply dissolved in the blood, rather they were held by chemical affinities. Furthermore these experiments showed that both pressure effects as well as chemical effects on the absorption of carbon dioxide by the blood serum and salt solutions were involved.[141] Thus the operation of both physical and chemical forces on the same process was not incompatible.

Meyer continued his physiological studies in Breslau (1858-1862) where he took over the direction of the chemical laboratory in the Physiological Institute and lectured on organic, inorganic, and physiological chemistry. It is of interest that Rudolf Heidenheim (1834-1897) who assumed the chair of physiology in Breslau in 1859 and continued his work on muscle and nerve physiology, still under the influence of du Bois-Reymond, apparently became interested in collaboration with Meyer that led to a joint publication.[142] It was during his stay in Breslau that Meyer completed his *Die modernen Theorien der Chemie und ihre Bedeutungen für die chemische Statik* (1864), an

[140] E. Fernet, "Du rôle des principaux éléments du sang dans l'absorption ou le dégagement des gaz de la respiration," *Ann. des sci. nature. (Zool.)* (1857) ser. 4, 13:, p. 151-152; Plate VII. On Fernet's method see Setchenow, "Beiträge," p. 3

[141] Meyer, *Die Gase des Blutes*, p. 49. On the importance of Meyer's method in the development of respiratory physiology see Lieben, *Geschichte der physiologischen Chemie*, pp. 268-9; Astrup and Severinghaus, *History of Blood Gases*, pp. 88-9; Culotta, *History of Respiratory Theory*, pp. 234-5

[142] R. Heidenhein and L. Meyer, "Über das Verhalten der Kohlensäure gegen Lösungen von phosphorsäuren Natron," *Studien des Physiologischen Institut zu Breslau*, Leipzig (1863) 2: 103-124. Although Heidenhein is generally regarded as an independent worker often opposed to the tendency to reduce vital phenomena to fairy simple physical and chemical processes and to their mathematical and physical interpretations, Meyer's brief collaboration with Heidenhein was fruitful in terms of further development of chemistry of the blood. See Cranefield, "Robert Bunsen, Carl Ludwig," p. 747. A number of Russian physiologists studied in Heidenhain's laboratory, Pavlov among them. On Heidenhain as a teacher and scientist, and his experimental research see I. P. Pavlov, "Pamiati Heidenhaina" ["In Memory of Heidenhain"], Speech on the meeting of the Society of Russian physicians in St. Petersburg, 23 Oct. 1897 in I. P. Pavlov, *Selected Works*, Iu. V. Natochin, et al, eds, Moscow, 1999, pp. 245-56

extraordinary clear statement of the fundamental principles of chemistry.[143] An excellent training in science with Bunsen and Kirchhoff in Heidelberg and in mathematical physics with Franz Neumann in Königsberg in 1856 determined Meyer's future career as a physical chemist.[144] Although his greatest achievement is tied to chemistry, particularly to his work on the periodic classification of elements,[145] Meyer's important physiological advances in blood gas research stimulated further development of accurate metabolic studies taken up by Ludwig and Sechenov.

There are some interesting parallels and contrasts in the scientific biographies of Sechenov and Meyer. As a chemically inclined physiologist, who had been inspired by Ludwig and Bunsen, Sechenov made significant improvements in chemical techniques that embodied an early example of the application of physico-chemical methods to the problems of experimental physiology. After a year spent in Mendeleev's laboratory in 1870, Sechenov was tempted to become a chemist: "To be the pupil of such a teacher as Mendeleev was of course both pleasant and useful, but I had already partaken of too much physiology to be disloyal to it, and I did not become a chemist."[146] Indeed, Sechenov spent more than ten years on the study on the absorption of gases by liquids, but he never abandoned physiology entirely. Today Sechenov is remembered primarily for his pathbreaking research in neurophysiology; however, his experimental studies on

[143] On Meyer's research in chemistry, see Partington, *History of Chemistry*, v. 4, pp. 889-91; on his research in blood gases, see P. P. Bedson, "Lothar Meyer Memorial Lecture," in *Memorial Lectures Delivered before The Chemical Society, 1893-1900*, London, 1901

[144] Franz Ernst Neumann (1798 -1895), professor of mineralogy and physics at the University of Königsberg, was a highly influential teacher and he made known many of his discoveries in heat, optics, electrodynamics, and capillarity during his lectures. He inaugurated the German *mathematisch-physikalische* seminar to introduce his students to research methodology; many of his students became outstanding scientists, Gustav Kirchhoff among them. J. Burke, in *Dictionary of Scientific Biography*, v. 10, pp. 26-9

[145] J. W. Spronsen, *The Periodic System of Chemical Elements: A History of the First Hundred Years*, Amsterdam, 1969, pp. 128-32

[146] Sechenov, *Autobiographical Notes*, p. 128

solutions were recognized as important by both Dmitrii Mendeleev and Wilhelm Ostwald, two of the leading advocates of the competing approaches, chemical and physical, to the nature of solutions.

Now let us look more closely at Sechenov's work at Ludwig's laboratory in 1858. He came there without a recommendation, but with a defined research topic: a study of the influence of the alcohol on the circulation of the blood and absorption of oxygen by the blood that required both physical and chemical methods of investigation. He was aware of Ludwig's published critisism on Karl von Vierord and Gabriel Valentin's strictly physical theory of gaseous transfer in the lungs, the so-called diffusion theory. Ludwig objected to their approach and method of quantitative estimates of red blood cells and lung capacity, particularly to Valentin's reliance upon the extensive numerical data as the application of arithmetic arguments to the living phenomena.[147] Lenoir rightly points out that during his studies in respiratory and urinary physiology, Ludwig increasingly began to perceive that the simple application of mechanics and physics could not account for the complex interrelations between physiological functions. [148] Ludwig's interest in chemical transformations in a functioning physiological context led him to encourage both of his most talented students, Meyer and Sechenov, to apply methods of organic chemistry to the problem of gaseous exchange in the blood. He believed that "in our field chemistry in the true sense of the word provides the prospects for the most significant advances."[149]

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[147] C. Ludwig, "Erwiderung auf Valentin's Kritik der Bermerkungen zu seinem Lehren vom Athmen und Blutkreislauf," *Z. f. rationelle Med.* (1846) 4: 183; J. Burdon-Sanderson, "Carl Ludwig," in Jones, ed., *The Golden Age of Science*, p. 411. See also Culotta, *History Respiratory Theory*, pp. 162-3

[148] Lenoir, "Science for the Clinic." in Coleman and Holmes, eds, *The Investigative Enterprise*, p. 154-5

[149] Ludwig to Jacob Henle, letter d. Vienna 18 October 1857, cited in Lenoir, "Science for the Clinic," in *ibid*, p. 155

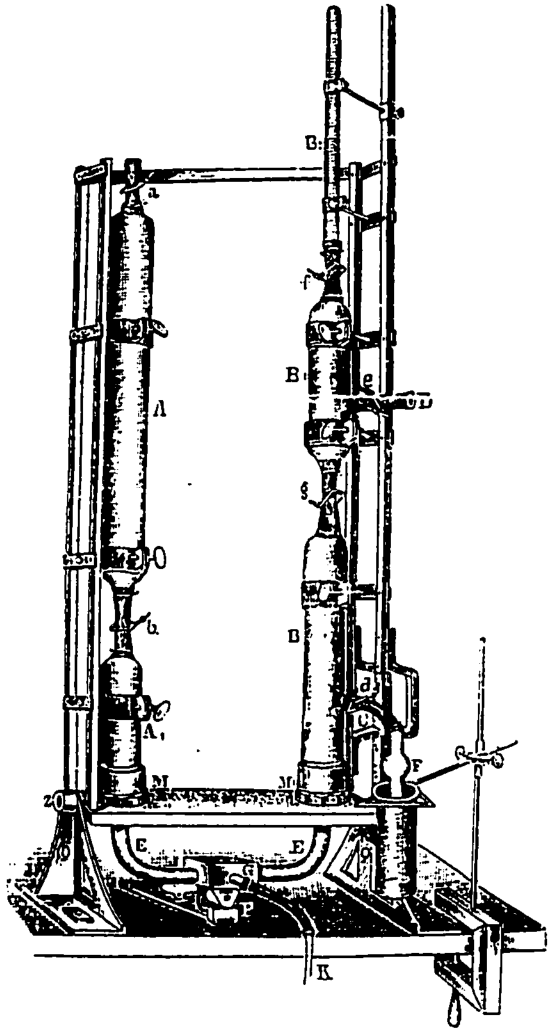

Figure 4. The blood gases apparatus of Ivan M. Sechenov. From I. Setchenow, "Beitrage zur Pneumatologie des Blutes" (1859) p. 295. For description see p. 77 opposite

During Sechenov's stay in Vienna, Ludwig was particularly interested in constructing a reliable device for measuring blood gases, as the apparatus reported by Magnus and Meyer had not met the requirement of precision.[150] Sechenov's experiments were aimed to determine the changes in the distribution of carbon dioxide under various conditions. His idea was to separate from the blood of a normal and intoxicated animal the gases contained in it and compare these values with each other. The removal of gases from the blood was a complex and tedious procedure. The commonly employed methods were: heating; formation of a vacuum for a gas in a solution by placing that solution in a closed vessel filled with a different gas, the so-called replacement technique; the addition of reagents; and the creation of a vacuum with air pumps or by the evacuation of mercury filled tubes (Toricellian vacuum). However, Sechenov was confronted by the major technical difficulties: uncontrolled heating led to coagulated blood proteins and entrapped gases; the added chemical reagents altered the natural structure of the blood; a long contact with mercury led to clumping and precipitation of the blood proteins (blood was usually defibrinated by shaking with mercury for a few minutes); and finally, foaming of the blood in the vacuum prevented complete removal of carbon dioxide.

Sechenov devised an improved model that eliminated the inaccuracy of Meyer's method: gases were removed practically entirely by exploiting a Torricellian vacuum without any chemical reagents. In the manner of Emil Fernet, the apparatus was combined with a vacuum pump for removing the mercury: the apparatus first was completely filled with mercury and then mercury was completely removed to form a

[150] C. Ludwig, "Zusammenstellung der Untersuchungen über Blutgase," *Med. Jahrbucher Wien* (1865) 9: 145-6

Torricellian vacuum. The variations in temperature and vapour pressure of mercury and the quantity of water present in the blood sample were evaluated, and the absorption coefficients of mercury for oxygen and carbon dioxide were taken into consideration. These produced the results of unprecedented accuracy. The other innovations were the coordination of the size of the blood sample with the size of the collection chamber, the length of the apparatus and the constancy of temperature throughout the experiment. Sechenov pointed to the advantages of his method: the operation of letting the mercury in and out and the boiling of the blood in a vacuum could be repeated the desired number of times until the boiling stopped giving off gas into the vacuum.[151] Sechenov's new model proved successful in test experiments, and Ludwig immediately ordered it for his laboratory.[152]

To summarize Sechenov's blood gas research in Vienna it should be stressed that Sechenov, following Ludwig, stated that the most accurate possible measurement of the gas content of the blood would make it possible to understand the complex phenomena underlying the process of respiration. The quantitative precision with elimination of insufficiencies of the existing methods fostered the design and improvement of the blood gas apparatus and the refinement of the method. The device and method became that tool of precision, which produced reliable results on the gaseous content of the blood. Sechenov's method of gas extraction and analysis were extremely accurate but tedious. The experiments with his apparatus were time and effort consuming: it took a whole day to extract gases from 100 ml of blood; in order to obtain accurate results, the evacuation had to be repeated many times to ensure the absence of gases in the blood. The blood-

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[151] Sechenov, "Beiträge zur pneumatologie des Blutes," pp. 11, 14-6
[152] Sechenov, *Autobiographical Notes*, p. 87

gas pump, a prototype of Van Slyke's apparatus,[153] was heavy and bulky, with a large amount of mercury, which should contain no air. Nevertheless, the results of the research undertaken in the late 1850s by chemically inclined physiologists such as Ludwig, Meyer, and Sechenov were impressive: the exact quantities of gases contained in the blood were estimated, the effects of both physical and chemical forces on the rate of absorption and retention of blood gases were discovered, and the concept of the role of pressure in the exchange of gases between the blood and the lungs were established for the first time.

Sechenov worked with the absorptiometric apparatus for years, pumping out carbon dioxide from the blood and investigating solutions in his laboratories in Odessa and then in St. Petersburg. Later he remarked, that it was these very experiments in Ludwig's laboratory in Vienna and "the long fussing with Meyer's apparatus" that became the reasons "that I devoted a very significant part of my life to problems of blood gases and the absorption of gases by liquids."[154]

5. "Alt Heidelberg, du feine ..."

Heidelberg and its old university, *Academia Ruperto-Carola* occupies a particular place in the history of nineteenth century Russian science: nearly all Russian

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[153] Donald Dexter Van Slyke (1883-1971) made his principle contribution to the development of clinical chemistry while he was the head of the hospital laboratory at the Rockefeller Institute in New York. His volumetric apparatus (1917) and his manometric apparatus (1924) laid bases for the introduction of gasometric technique in the hospitals throughout the world. As in the early blood-gas pumps (including Sechenov's one) a Torricellian vacuum was first produced. Then the instrument could register the changes in volume or pressure that the release and subsequent absorption of the gases gave rise to. Astrup and Severinghaus, *History of Blood Gases*, p. 252; see also R. E. Kohler, *From Medical Chemistry to Biochemistry*, Cambridge, 1982, pp. 238-9, 242-3

[154] Sechenov, *Autobiographical Notes*, p. 87

intellectuals of the 1860s studied there or at least visited the famous university town. The historian and jurist Sergei Svatikov in his unpublished paper *Russische Studenten in Heidelberg*, written in 1906, noted: "For a hundred years Heidelberg was home for Russian youth seeking for knowledge. More than a thousand Russian students studied at the old University during that period, and having returned to Russia they brought back with them precepts of the great representatives of German science."[155] The "Heidelberg period" is well documented in the letters, memoirs, and diaries of Sechenov, Mendeleev, Borodin, and Chicherin. Usually, Soviet historians of science in describing the 'Heidelberg period' of such scientists as Mendeleev and Sechenov like to stress particularly two things: the originality of their research in Heidelberg and the development of their materialistic outlook due to the reading of literature forbidden in Russia.[156] However, these writers omitted one yet important moment: the atmosphere of established academic freedom of the old University so lacking in Russian educational institutions. But even more important for the young Russian naturalists of the 1860s were the laboratories that offered not only appropriate research facilities but also well-defined training programs, and the laboratory leaders such as Helmholtz, Kirchhoff, Bunsen, and Erlenmeyer, whose distinctive investigative practice influenced and inspired those who had studied with them.

For nearly five hundred years of its existence, Heidelberg University was one of the centers of scientific and philosophical thought in Europe. The small town in southern Germany located in the picturesque valley of the river Nekkar with the grand ruins of

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[155] Svatikov, *Russische Studenten*, p. 78

[156] N. A. Figurovskii, ed, "Dnevniki D. I. Mendeleeva 1861 i 1862" ["Mendeleev's Diaries of 1861 and 1862"] in S. I. Vavilov et al, eds, *Nauchnoe nasledstvo [Scientific Heritage]*, in 3 vols. Moscow, 1951, v. 2, pp. 95-111); Iaroshevskii, *Sechenov*, pp. 41-3

the medieval castle had been, according to Svatikov, a favourite place for Russian students since the mid-eighteenth century. The reform activities of Alexander I at the beginning of the nineteenth century brought in its wake an interest among Russian intellectuals in the juridical sciences. The faculty of jurisprudence with its famous professors of public law and political economy attracted Russian students at that time most of all. In the late 1850s with the rapid growth of experimental sciences the chemical and physiological laboratories of Heidelberg University acquired fame for scientific research and education.[157] According to Chicherin, who visited Heidelberg in 1858,

> in this small corner of Germany there were so many outstanding scholars that any university would envy. It was a scientific center in every sense of the word. Besides Mohl, here taught the famous Mittermeier, one of the most learned criminologists of Germany, who was already in his old age; a classicist Vangerow, the best expert in pandects, who trained a whole generation of jurists; Geisser, a historian who taught at that time the history of the French revolution. In other branches of science the University was famous through other even more celebrated names. Often one could see three scholars, luminaries in natural sciences of the time, walking together: Helmholtz, Bunsen, and Kirchhoff.[158]

At that time, a large group of young Russian scientists, most of them chemists and naturalists, studied there. The core of the so-called 'geidel'bergskii kruzhok' [Heidelberg circle] were Mendeleev, Borodin, Sechenov, and Junge. According to Borodin, "Russians are divided into two groups: those who do nothing, the aristocrats, the Golitsins, the Olsuf'evs, etc., and those who study. These stick together and meet for

[157] On the institutionalization of experimental physiology in Heidelberg University, see A. Tuchman *Science, Medicine, and State in Germany. The Case of Baden*, Oxford, 1993, pp. 113-51
[158] Chicherin, *Vospominaniia*, p. 88. On Carl Joseph A. Mittermaier (1787-1867), see *Neue Deutsche Biographie*, v. 17, pp. 584-585; on Carl Adolf Vangerow (1808-1870), see *Allgemeine Deutcsche Biographie*, Leipzig, 1895, v. 39, pp. 479-480. Pandects (from L. *pandecta*, Gr. *pandektes* all-receiving) is the digest on decisions, writings, and opinions of Roman jurists, the major compilation of the Roman civil law.

dinners and for evenings."[159] The young people discussed questions concerning the growth of science in Russia, and the results of their own experimental investigations. Sechenov recalled that at the meetings, usually held at someone's apartment, they used to read aloud favorite passages from Alexander Pushkin and Alexander Herzen, and when a discussion turned to Russian affairs, hot and noisy arguments occurred, interrupted by stories and recollections. Sometimes the young people criticized German professors and ridiculed German students with their duels and schoolboy tricks, and local society for its tendency to gossip.[160] At such meetings Borodin used to entertain the audience with piano music; knowing that Sechenov was passionately fond of Italian operas, he played all the principle arias from Rossini's *Il Barbiere di Siviglia.* Sechenov remained a passionate lover of Italian operas, and later shared his reminiscences about the famous Italian singers Ermina Frezzolini and Adelaide Borghi, whom he had so passionately admired in his youth:[161] after performance he and his comrade students used to arrange a wild ovation at the exit of the theater, and even unharnessed horses to pull the carriages with their favourite actresses themselves.[162]

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[159] Borodin to his mother, letter d. Heidelberg, 25 November 1859, in S. A. Dianin, ed, *Pis'ma A. P. Borodina. 1857-71 [Letters of A. P. Borodin]*, Moscow, 1927-28, p. 36

[160] *Ibid,* see also Sechenov, *Autobiographical Notes,* pp. 91-2

[161] Adelaide Borghi (1826-1901), Italian mezzo-soprano, sang in Vienna, Paris, and Italy. She was famous for her full-toned, vibrant voice and passionate temperament. Ermina Frezzolini (1818-1884), Italian soprano, was admired for her smooth and expressive legato singing (exploited by Verdi). She was noted too for her power and brilliance, in modern manner, and she excelled in dramatic roles. See S. Sadie, ed, *The New Grove Dictionary of Opera*, New York, 1992, pp. 302, 551. An interesting account on the debates between adherents of Italian operas and German music is given in V. P. Botkin "Ital'ianskaia i germanskaia muzyka" ["Italian and German Music"], see V. P. Botkin, *Literaturnaia kritika,* pp. 30-9

[162] Sechenov, *Autobiographical Notes,* pp. 70-1. On Sechenov 's love of music, see "My Friends" in A. V. Nezhdanova, *Materialy i issledovaniia [Material and Reseaches],* Moscow, 1967, pp. 59-65. Antonina Vasil'evna Nezhdanova (1873-1950) represented the famous Russian vocal school at the end of the nineteenth -beginning of the twenties centuries: a singer at the Bolshoi Theater (lyrico-coloratura soprano), professor of the Moscow Conservatory (doctoral degree in Art History). Nezhdanova was a close friend of the Sechenovs during the 1890s in Moscow.

According to Sechenov, Borodin carefully concealed the fact that he was a serious musician. Nevertheless, during 1860 and 1861 he composed three chamber-instrumental ensembles that were first performed in Heidelberg. In a letter to his mother, Borodin mentioned that he had acquired the reputation of a musician and played much chamber music there. At one of the musical parties he met his future wife Ekaterina Protopopova (1832-1887), a talented pianist who came to the Baden-Baden spa for treatment. Both were fond of German music and frequently visited Mannheim and Baden-Baden for concerts of Robert Schumann's music and the operas of Richard Wagner.[163]

The Heidelberg period was of crucial importance for Russian chemistry, and for the introduction of the chemical practicum into the teaching program of the Medico-Surgical Academy in particular. It was in Heidelberg that the idea of creating a Russian Chemical Society first emerged, and the 'Heidelberg circle' itself, according to Borodin, already represented a small society of young chemists and naturalists.[164] In the summer of 1860 Nikolai Zinin, the leading professor of the St. Petersburg Medico-Surgical Academy, returning from a trip, undertaken in order to inspect the buildings and equipment of some foreign chemical laboratories, came to Heidelberg. In September of 1860 Zinin, Borodin, and Mendeleev represented Russian chemistry at the International Congress of Chemists in Karlsruhe. Mendeleev's letter from Heidelberg to his teacher,

[163] Borodin to his mother, letter d. Heidelberg, 31 March 1860, in Dianin, *Pis'ma Borodina*, p. 38. For a list of Borodin's musical compositions and his music during 'Heidelberg period,' see S. A. Dianin *Borodin. Zhizneopisanie, materially i dokumenty [Borodin. Biography, Materials and Documents]*, Moscow, 1960, pp. 44-9, 358: these were a sonata for 'cello and piano in B Minor, a string sextet for two violins, two violas, and two violoncellos in D Minor, and a trio for violin, 'cello and piano in D Major, which bear influence of Mendelson's music. Borodin's major musical work "Prince Igor" was written during his professorship at the Academy. Borodin's sudden death in 1887 from heart attack at the ball at the Academy prevented him from finishing the opera, it was edited by N. A. Rimskii-Korsakov (1844-1908) in 1890

[164] M. N. Mladentsev and V. E. Tishchenko, *D. I. Mendeleev, ego zhizn' i deiatel'nost' [D. I. Mendeleev, his Life and Work]*, Moscow, 1938, pp. 171, 180-182, 194, 250-58

professor of chemistry A. A. Voskresenskii, contains a detailed account of the sessions of the congress in Karlsruhe and what it had accomplished. Coming home from abroad, the young Russian chemists continued their meetings in St. Petersburg. This group known as *khimicheskii kruzhok* [chemical circle] was active till 1868 when the Russian Chemical Society was founded.

Heidelberg had comfortable and, in a way unique, conditions for studies in chemistry. Mendeleev was reluctant to return and applied for an extension. In his letter from Heidelberg on December 1860 to Trustee of the St. Petersburg education district, he indicated two major reasons why it was so difficult for natural scientists in Russia to pursue experimental work, first, lack of time: they all were busy with outside matters to earn their living, and at best were part-time scientists. The second reason was lack of means and research facilities:

> In Russia the lack of means occurs first, because even in St. Petersburg one can find no good mechanic, no good druggist, therefore you have to do a lot of unskilled work that takes so much energy and time; second, ...we do not have laboratories at hand. Here anyone must have his own laboratory, and professor has a university laboratory. Therefore in small Heidelberg there are five private laboratories. ... Thirdly, the majority of our institutional laboratories have no assistants as it is accepted in any laboratory abroad: to teach students the first manipulations, supervise the analyses, prepare experiments and fulfill preparatory work – all this in our laboratories is a responsibility of a professor.[165]

Indeed, there were a few chemical laboratories in St. Petersburg, at the University, and in some specialized institutions such as the Medico-Surgical Academy, the Artillery Academy and Technological Institute, but no independent private laboratories. The educational laboratories had not much equipment for experimental

[165] Mendeleev to Trusty, St. Petersburg Educational District, letter d. Heidelberg, September 1860, cited in Mladentsev and Tishchenko, *D. I. Mendeleev*, pp. 224-6

work and were understaffed by mechanics, who keep the laboratory in working order and assistants, who would relieve teaching duties of professors, a usual practice in Germany. In Heidelberg, every possible opportunity was available for acquiring experimental skills or perfecting them in the university laboratory and in private laboratories or even to set up a small laboratory particularly for their own research. Here there was plenty of time, and freedom for individual research, and finally, Russian scientists had their mission money: they could afford instruments and reagents for their work and enjoyed freedom from formal duties. Borodin and Mendeleev often mentioned about the low cost of living in Heidelberg, and the availability of instruments and reagents at a relatively low price. Their letters contain a detailed account of the mechanics and glassware workshops in Paris and Bonn, and pharmaceutical shops in Darmstadt and Paris alongside descriptions of the quality and prices of products available at that time on the chemical instruments and reagents market.[166]

For a young, though experienced, chemist such as Mendeleev, Bunsen's university laboratory with a lot of students, all of them beginners, was of 'no value'. Mendeleev had received solid training in the natural sciences at the St. Petersburg Main Pedagogical Institute: with A. A. Voskresenskii in chemistry, Heinrich Lenz in physics, and M. V. Ostrogradskii in mathematics, all luminaries in Russian science. His teachers recognized his talents: in 1859 after two years of work as a private docent at St. Petersburg University, Mendeleev was sent abroad for advanced study in chemistry. Sechenov recalled, "Mendeleev, of course, became the leader of our group, as despite

[166] Mendeleev to to his colleague L. N. Shishkov, letter d. Heidelberg, December 1859, cited in Mladentsev and Tishchenko, *Mendeleev*, pp. 159-62. See also Borodin's accounts on his studies abroad to President of the Medico-Surgical Academy Dubovitskii, for 1860-1862, in N. A. Figurovskii and Iu. I. Solov'ev, *A. P. Borodin. A Chemist Biography*, Ch. Steinberg and G. Kauffman, transl., Berlin, 1988, pp. 137-8, 142-6

his young age [25 years old] he was already an established chemist and we were just students."[167]

In Heidelberg Mendeleev was investigating capillary phenomena and the deviations of gases and vapors from the laws of perfect gases. In Bunsen's laboratory, according to Mendeleev, even the weights were rather bad, and there was no neat quiet place to work with the delicate equipment that he used for his research. Therefore he set up a small laboratory in his apartment with his own equipment and even furnished it with gas. But what Mendeleev did value in Bunsen's laboratory was 'a school itself, with a lot of workers'[168] and the spirit of science and freedom of the old university.

For Borodin, a physician who had got training in Zinin's chemical laboratory at the Medico-Surgical Academy, the goals were quite different from those of Mendeleev. Borodin was sent abroad by the Conference of the Academy in order to improve his education in natural sciences, to be prepared to teach chemistry at the Academy according to requirements for the contemporary education of physicians. The discipline of chemistry and the simultaneous development of other experimental sciences such as physiology and physics were promoted at the Medico-Surgical Academy by Nikolai Zinin. As one of the leading reformers at the Academy, he encouraged Borodin, the most talented of his students, to report on achievements elsewhere in order to justify his demand for resources for Academy's chemical laboratory. Zinin also wanted Borodin to

[167] Sechenov, *Autobiographical Notes*, p. 91

[168] Mendeleev to Shishkov, letter d. Heidelberg, December 1859, in Mladentsev and Tishchenko, *Mendeleev*, p. 116. On Mendeleev laboratory in Heidelberg see also, Borodin to his mother, letter d. Heidelberg, November 1859, in Dianin, *Pis'ma Borodina*, p. 34, and in Sechenov, *Autobiographical Notes*, p. 91. Mendeleev mentioned Bunsen in his *Dnevniki* as "very nice as usual." see Vavilov et al. eds. *Nauchnoe nasledstvo*, v. 2, p. 153. According to Partington, Bunsen's lectures, which included much of his own work, had very little alteration with time. Bunsen never in his lectures mentioned the periodic law discovered by his own students Mendeleev and Lothar Meyer in 1869-1870, who were jointly awarded the Davy Gold Medal for their achievements by the Royal Society of London in 1887, see Partington, *History of Chemistry*, v. 4, p. 283

acquire advanced training in methods relevant to teaching chemistry in the medical institution. Zinin's Letter of Instruction to Borodin is telling in this respect:

> 1. To study thoroughly several special research methods which are of particular importance for both pure and applied chemistry, i.e. methods of gas analysis, technique of analysis by titration of solutions, carrying out of chemical reactions in sealed tubes under high pressure. For that you must visit the laboratories of Bunsen in Heidelberg, of Wurtz, Berthelot, and Saint-Claire Deville in Paris, and of Hofmann in London.[169]
> 2. To study the application of chemistry to physiological and medical sciences, you must visit the laboratories of Scherer in Würzburg and Liebig in Munich.[170]

Borodin thought of himself as a prepared chemist, not a beginner, therefore he favoured the private laboratory of Carl Emil Erlenmeyer (1825-1909), a private-docent at the University who had also a section and equipment for gasometry. For Borodin, as for Mendeleev, studies in Bunsen's university laboratory proved to be of no interest or convenience: the equipment in the laboratory was set up for study of analytical methods developed by Bunsen himself; there were too many students, hence too much time was wasted to use ovens and apparatus. Reading Borodin's official letters to the Conference of the Academy one gets an impression that he wanted to justify his preference for study at a private laboratory paying twice as much as for a public laboratory, and to use his own equipment, reagent and vessels which he had bought in Paris and Darmstadt.[171] Borodin presented a rather harsh critical account of the university laboratories and its leaders:

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[169] August W. von Hofmann (1818-1892), after returning from London got the chair at Berlin University. He created his own school of chemists who were interested primarily in experimental organic chemistry and the industrial applications of chemistry. W. H. Brock, "A. Hofmann," in *Dict. Sci. Biog.*, vol. 5, pp. 461-3

[170] Cited in Figurovskii and Solov'ev, *Borodin*, pp. 136-7

[171] Borodin bought an apparatus for the work in sealed tubes from Marcellin Berthelot in Paris and reagents from *E. Merk*, a chemical pharmaceutical shop in Darmstadt. *E. Merk* was formed in 1827 from the company *Engel-Apotheke* which had been founded in 1654 and had been in the possession of the Merk family since 1668. See *Deutsches Apotheken-Museum im Heidelberger Schloss*, Heidelberg, 2000.

Bunsen, limiting himself to a narrow frame of development of a few analytical methods for physico-chemical research, lost any interest in chemistry as a science (especially organic chemistry) and long ago fell behind in it. ...I do not attend any lectures. ...Bunsen and Kirchhoff are too elementary, and Helmholtz gives, according to duty, a very elementary course on the history of development instead of on his physiological research.[172]

Borodin visited the lectures primarily to get acquainted with their manner of instruction and also to see the performance of experiments. He also visited Bunsen and Kirchhoff's laboratory unofficially and observed their work in the application of a gas flame to the qualitative and quantitative determination of potassium, sodium, lithium, etc. in various minerals that laid the foundation of spectral analysis.

In Erlenmeyer's laboratory Borodin had favourable conditions for his research: a convenient schedule, and excellent equipment. Apparently Erlenmeyer and Borodin had much in common: both had studied medicine and both were converted into chemists by their teachers, Liebig and Zinin, respectively, the leading organic chemists of the time in Germany and Russia. Finally, Erlenmeyer's personality, and his close association with the leading structural chemists August Kekulé and Hermann Kolbe were of great interest to Borodin. In their Heidelberg time both Borodin and Mendeleev published in Kekulé's new journal *Kritische Zeitschrift für Chemie, Physik und Mathematik*, which Erlenmeyer edited. Interestingly, of its 150 subscribers since 1864, half were Russians.[173]

Among members of the 'Heidelberg circle' it was Sechenov who most appreciated training in Bunsen's laboratory. For a physiologist engaged in the research

[172] Cited in Figurovskii and Solov'ev, *Borodin*, p. 137
[173] Borodin published three articles in 1860 and 1862 on the derivatives of benzidine in Erlenmeyer's *Zeitschrift*. On Mendeleev's relationship with Erlenmeyer, see Mendeleev, *Dnevniki*, in Vavilov, et al, eds, *Nauchnoe nasledstvo*, v. 2, p. 112-26. In 1868 Erlenmeyer got a chair of chemistry at the Munich Polytechnic School. He was coauthor of the three-volume *Lehrbuch der organischen Chemie* (1867-1894) and editor of the *Zeitschrift für Chemie und Pharmazie* and of Liebig's *Annalen der Chemie*. On Erlenmeyer's research and editorial activities, see Rocke, *The Quiet Revolution*, pp. 250- 7; see also A. Costa, "Erlenmeyer," in *Dict. Sci. Biog.*, vol. 4, pp. 399-400. On his Heidelberg time, see "Personalakten 1857-1863," in the *Heidelberg University Archive*, PA 1524

on blood gases, studies of gasometry at Bunsen's laboratory were indispensable. As we have seen earlier, the methods of quantitative gas measurements became immensely important for the respiratory physiology research of the time. As Cranefield has noted, Ludwig was deeply influenced by Bunsen in whose laboratory in Marburg he had been trained in the exact sciences. Ludwig's later work on blood gases was a specific result of the fact that work on gas analysis had been so active in Bunsen's laboratory during his Marburg years of 1838-1845.[174] Ludwig certainly influenced Sechenov's decision to study with Bunsen, and Sechenov went to Heidelberg after he had completed his research in Ludwig's laboratory in Vienna. There can be no doubt that Sechenov's attraction to chemistry received a first impetus from Bunsen's famous course of lectures on *Allgemeine Experimentalchemie.* It was in Bunsen's laboratory that Sechenov acquired an introduction to precise chemical investigation, which he later perfected in Mendeleev's laboratory, and which was to dominate in his research of blood gases and salt solutions. Of Bunsen himself, Sechenov said with particular warmth:

> Knowing that I was a medical student, Bunsen suggested that first of all I study alkalimetry and analysis of mixtures of atmospheric air with CO_2. I knew of Bunsen's perfect goodness and simplicity, and talked to him without being embarrassed. Bunsen lectured excellently; he had the unconquerable habit at lectures of smelling the odorous substances described, however harmful and bad the odors were. They recounted how once he smelled something until he fainted. Long ago he had paid for his weakness for explosive substances with his eye, but at any opportunity he produced explosions in his lectures. He was a general favourite, and the students called him always Papa Bunsen, although he was not yet an old man.[175]

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[174] On Marburg years of Bunsen, see F. Kraft, "Robert Wilhelm Bunsen in Marburg," in F. Kraft, ed, *Bunsen-Briefe in der Universitätsbibliothek Marburg,* Marburg, 1996, pp. 71-83; see also Cranefield "Robert Bunsen, Carl Ludwig and Scientific Physiology" in F. Kao, et al eds, *Research in Physiology,* p. 745

[175] Sechenov, *Autobiographical Notes,* pp. 88, 90-1. Former pupils of Bunsen always spoke of him with admiration. Henry E. Roscoe (1833-1915), a distinguished English chemist, who studied and worked with

Bunsen had an excellent knowledge of mathematics and physics, which he used in his numerous investigations. In his research and his teaching, he emphasized the experimental side of science. He was an expert glass blower and made the most of his famous apparatuses and devices. Sechenov had much in common with his distinguished teacher: he had background in mathematics and physics and during his research career he designed and improved a number of devices, including an absorptiometer, a stationary gas analyzer for investigation of expired air, and a portable gas analyzer. Later during one of his visit to Berlin, Sechenov took lessons from the noted glassblower Geissler, and used to make glass parts for his devices himself.[176]

In his *Autobiographical Notes* Sechenov mentioned that Ludwig in his letters to Heidelberg always sent his "heartfelt regards to Bunsen and Helmholtz."[177] During his short stay in Helmholtz's laboratory Sechenov worked on the problem of determination of the permeability of the transparent media of the eye to ultraviolet rays. Later Helmholtz mentioned in a letter to Brücke about Sechenov's successful research on the fluorescence of the crystalline lens. The kind Ludwig in his letter to Sechenov encouraged him to further instructive contacts with Helmholtz, and mentioned that "...schon schreibt er [Helmholtz] mir, dass Sie hat ihm gut gefallen."[178] Even a brief acquaintance with Helmholtz produced great impression on Sechenov, like he "experienced on seeing for the first time the Sistine Madonna in Dresden... From his

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Bunsen (from 1855), was reported to say: "As an investigator he was great, as a teacher he was greater, as a man and friend he was greatest," see Partington, *History of Chemistry*, v. 4, p. 282

[176] The Memorial Museum of I. M. Sechenov at the Moscow Medical Academy presents some apparatus made by Sechenov in collaboration with M. N. Shaternikov, and a glass-blowing table that Sechenov used in his work. See, *Pamiatniki nauki i tekhniki v muzeiakh Rossii [Relics of Science and Technology in Russian Museums]*, Part 2, Moscow, 1996, pp. 56-7 The apparatus constructed by Sechenov at Ludwig's laboratory is also preserved here. It is reported that Sechenov brought it from Vienna to the St. Petersburg Medico-Surgical Academy in 1860

[177] Sechenov, *Autobiographical Notes*, p. 88

[178] *ibid*, p. 90

quiet figure with thoughtful eyes breathed peace as if he were not from this world."[179]

Sechenov, Borodin, and Mendeleev were in their twenties when they studied in Germany. It is appropriate to say a few words about their interests other than science to feel the flavor of the time. They enjoyed traveling together across Europe during vacation without worries and constraints, with a feeling of freedom in their souls. The picturesque mountains of the 'Saxon Switzerland' and the Tyrolean villages, poetic beauty of the Alpine peaks, glaciers, waterfalls, and lakes, all these wonders of nature were unfolded in their letters.[180] A remarkable place in the letters, diaries and recollections is given to images of European art: the galleries and museums of the Vatican, Milan, and Florence, cathedrals with their frescoes and sculptures of the Renaissance, the graceful architecture of Venice, and the beautiful environs of Naples. In Rome, Sechenov communicated with young Russian artists in their usual place of gathering, *Caffe Greco*, and spent much time with the artist Alexander Ivanov who at that time was working on a series of pictures for Strauss's *Das Leben Jezu.*[181] Mendeleev was greatly impressed by the rich collections of Egyptian and Greek art in the Berlin *Neues Museum*. It was all a feeling of fun and excitement that mixed art and science as a new experience for them.

The letters are full of interesting remarks and comparisons of the cities they visited, modes of life, and national peculiarities in cuisine and entertainment. As if with

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[179] *ibid*, p. 89; see also I. M. Sechenov, " German fon Gel'mgolts kak fiziolog" ["Hermann von Helmholtz as a Physiologist"] in *Russkaia Mysl' [Russain Thought]* (1894) 12: 28-37

[180] Dianin, *Borodin*, pp. 44-61; see also Dianin, *Pis'ma Borodina.*, pp. 25- 57; Sechenov, Autobiographical *Notes*, pp. 74-6; Mendeleev. *Dnevniki*, in Vavilov et al, eds, *Nauchnoe nasledstvo*, v. 2, pp. 126-7

[181] Alexander A. Ivanov (1806-58) the Russian artist, famous for his monumental painting *The Appearance of the Saviour to People* (1837-57, *Tret'iakovskaia Gallery*, Moscow) that might bear an influence of Strauss's interpretation of the personality of the Christ. Strauss David Friedrich (1808-74), the German theologies and philosopher, in his *Das Leben Jezu* (1835-36) refuted the authenticity of the Gospels and presented the Christ as a historical person.

an ironic smile, the young men shared impressions on how they had got acquainted with the 'vain side of Parisian life' enjoying a good time at Christmas there: dance classes in *Closerie de lilas*, theaters with supper after the performance, and masquerade balls with girls in the costumes of Spanish gypsies, bayadères, etc. It was an unforgettable time for all of them.

Sechenov would always remember the 'romantic country' of his youth: "one could not help loving the Germany of that time with its simple, good, open-hearted inhabitants. Germany presents itself for me even now in the form of the fulfilled peace and quiet of a landscape, at the time when the lilac, apple trees and cherry trees were in bloom, showing as white spots against the green background of the clearing cut up by vistas of poplars."[182] It seems that it was Heidelberg that had a particular charm for the young people. Mendeleev's *Geidelbergskii Dnevnik* is telling in this respect: alongside scrupulous details on his work, scientific discussions, visits, and personal issues, it conveys a very special emotional atmosphere of that time. Here is the last entry before his departure from the town where he spent two years: "Farewell to Heidelberg...A mist covered the valley, it was a cold morning, clear mountains, and a haze behind the sun... I haven't noticed anything around me on my way to Darmstadt – my eyes were full of tears...all were dreams of the past."[183]

I will close this chapter with an impression I got, while reading letters and memoirs of Sechenov, Mendeleev, and Borodin, that is best expressed by Svatikov, who

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[182] Sechenov, *Autobiographical Notes*, p. 95. Sechenov's companion in Heidelberg, D. I. Mendeleev wrote ironically: "Sechenov likes Germans a little bit more than me, defends them and even German women, but it is so, apparently he wants out of Russian habit to show his gratitude for German hospitality." See, Mendeleev to the Protopopovs, letter d. Heidelberg, 30 January 1860, cited in Mladentsev and Tishchenko, *Mendeleev*, pp. 190-1

[183] Mendeleev, *Dnevniki*, in Vavilov et al, eds, *Nauchnoe nasledstvo*, v. 2, p. 126

belonged to a later generation of Russian Heidelberg students: "...all of them without exception, looking back at their youth, remember the University in the same way, as a stronghold of free science, and the old town between the mountains in white bloom, sweet-smelling, the symbol of bright youth, so beautiful and so irrevocably passing...Alt Heidelberg, du feine..."[184] Though with a touch of romantic sentiment, the quote reflects a feature relevant to our story: Heidelberg of the late of the 1850s represented for the young Russian scientists the rigor of research scholarship and the academic freedom of the German science, ideals they hoped to bring back home. For Sechenov and Borodin in particular, it was the teaching and research laboratory model that became the principle innovative feature of their activities at the St. Petersburg Medico-Surgical Academy.

Now we shall see how the German laboratory model was adapted to the Russian setting. We have to keep in mind that it was no novelty for Russia to look to the West in search of ideas for the educational reforms. In its organizational plan and its goals, Moscow University, founded in 1755, was a true embodiment of the spirit of the Western academic tradition. Later, the new universities in Kazan, Kharkov, and St. Petersburg, founded at the beginning of the nineteenth century, in their conception and organization were modeled after Göttingen University, which as Napoleon once remarked belonged not to Germany but to all Europe.[185] The reformation of the St. Petersburg Medico-Surgical Academy in the late 1850s followed the example of the Prussian Medico-Surgical Academy, which was institutionally and intellectually connected to Berlin University. The essential part of the Academy's modernization was the emulation of the German laboratory medicine that was instrumental in setting the

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[184] Svatikov, *Russische Studenten*, p. 78
[185] Milukov, "Universitety v Rossii," p. 789, cited in Vucinich, *Science in Russian Culture*, v. 2, p. 194

pattern for the emphasis on practical training in natural sciences and teaching-research standard for the professoriate. In the next chapter we will examine how it came that the Medico-Surgical Academy happened to be the right place in the right time for successful introduction of these innovative practices.

Emperor Alexander II in 1857 committed the Conference of the St. Petersburg Medico-Surgical Academy to work out the new regulations in order to put medical sciences in Russia on the same level of perfection as in Germany and France.

I. T. Glebov, Vice-President of the St. Petersburg Medico-Surgical Academy, *Kratkii obzor deistvii Imperatorskoi Meditsinsko-Khirurgicheskoi Akademii za 1857, 1858 and 1859 gody v vidakh uluchsheniia etogo zavedeniia [A Brief Survey of the Activities on the Improvement of the Imperial Medical Surgical Academy for 1858, 1857, and 1859]*, St. Petersburg, 1860, pp. 4-5

Only deserving representatives of science should teach at an institution of higher learning.

P. A. Dubovitskii, President of the St. Petersburg Medico-Surgical Academy, *ibid*, p. 6

Chapter II

The St. Petersburg Medico-Surgical Academy and the Development of Experimental Sciences in Russia

1. The Winds of Change: The Reformation of the Medico-Surgical Academy

The laboratories for physiological and clinical research and teaching created by Sechenov and Botkin in 1860 within the military medical educational system were the first Russian laboratories patterned on the German model. That claim alone is not sufficient for insight into the character of what proved crucial in the development of laboratory sciences in Russia during the second half of the nineteenth century. At the core of research activity of a physiologist or physiologically oriented clinician was observation and experimentation which required substantial material resources: space, supplies, and particularly instruments and apparatus. To provide these means for the laboratory, the support of people who represented governmental and educational structures was needed. In our case, it was the military, traditionally the most powerful faction in the Russian government, which pushed for the necessary funding and which was pivotal for the research and teaching career of Botkin, Sechenov, and Cyon, the early innovators in Russian experimental physiology and medicine. The distinctions drawn here between research and pedagogical activities of the main protagonists, and the institutional framework and the state interests are somewhat unreal and are used only to visualize the process of the emergence and growth of laboratory based medicine in Russia.

The St. Petersburg Medico-Surgical Academy is central to understanding the spread of the physiological laboratory first promulgated at the Academy, and within the next decade emulated at the universities. The advances we are going to examine here were not introduced elsewhere: indeed, in the late 1850 the uniquely favorable conditions for the development of experimental sciences could not be repeated at any Russian university. There were two main reasons for that. As a specialized elite institution that trained physicians for the army and the fleet, the Academy had special privileges and traditions. It was subordinated to the War Ministry, not to the Ministry of Education as were the Russian universities. Therefore, first, the Academy received much more material means from the Ministry of Finance for the development of sciences and training of highly qualified physicians in accordance with the new demands of the Reform era. Second, the Academy was saved from the petty guardianship of the officials,[186] which was characteristic of the style of guidance of the Russian universities under the Ministry of Education.[187]

The St. Petersburg Medico-Surgical Academy was one of the oldest higher medical institutions in Russia. It was founded on the basis of the St. Petersburg Medico-Surgical School and the St. Petersburg Land-forces and the Kronstadt Admiralty

[186] Rectors of the universities held responsibilities for daily control of teaching according to the programs approved by the Ministry of Education. Special reports on the " the spirit and trend" of professors' teaching based on the professors' manuscripts and students' notes had to be submitted annually to the Ministry. Students were under supervision of the Inspector (chiefly a military official of the tenth rank, like the Ordinary professors). See Eimontova, *Russkie universitety*, pp. 40- 5

[187] Some of the institutions of higher education (closed schools, military academies, specialized institutes) attached to the ministries other than Ministry of Education traditionally allowed their students a great deal more freedom than the students in the universities enjoyed. The closed schools – Pazheskii Korpus, the Tsarskosel'skii Lycee and Uchilishche Pravovedeniia (the Institute of Law) - to train the government elite were open only to hereditary nobles. The specialized institutions prepared trained specialists mainly for state services. The oldest and more important in St. Petersburg were the Mining Institute (1773) and the Medical-Surgical Academy (1798). The majority of students in these institutions came from estates of gentry and civil service, see Eimontova, *Russkie universitety*, pp. 31-3; S. Kassow, *Students, Professors, and the State in Tsarist Russia*. Berkeley, 1989, pp. 18-20

hospitals attached to it. By 1795, the course of training at the Medico-Surgical School included all the courses taught at the medical faculties of French universities. There were seven chairs at the School: mathematics and physics, chemistry and botany, anatomy and physiology, materia medica and pharmacy, pathology and therapy, surgery, and obstetrics. Most professors had taken their medical degrees in Paris or Strasbourg. In 1798 the school was transformed into the Medico-Surgical Academy with the right to award doctoral degrees in medicine The Academy inherited from the school not only students, professors, and teaching programs but its distinctive feature, a clinical approach to teaching medicine. Due to its new status the Medico-Surgical Academy became the leading medical institution in the Empire.[188]

Besides the Academy, physicians were also trained at the medical faculties of the universities in Moscow,[189] Dorpat,[190] Vilno,[191] Kazan, Kharkov, and Kiev. In the first half of the nineteenth century the medical faculty of Dorpat University ranked among the best in Russia as it preserved a spirit of independence, traditional for German universities. Most of the professors there were Germans, some of them of high scholarly

[188] On the history of medical education in Russia in the eighteenth century, see "Istoricheskii ocherk meditsinskogo obrazovaniia v Rossii do uchrezhdeniia Mediko-khirurgicheskoi Akademii v 1789 godu" ["A Historical Survey on Medical Education in Russia before the Foundation of the Medico-Surgical Academy in 1798"] in N. I. Ivanovskii, ed, *Istoriia Imperatorskoi Voenno-Meditsinskoi (byvshei Medico-Khirurgicheskoi Akademii za 100 let. 1798-1898 [A History of the Imperial Military-Medical (former Medico-Surgical) Academy for a Hundred Years]*, St. Petersburg, 1898, pp. 15-42; see also, B. Mirskii, *Meditsina Rossii 16-19 vekov [Russian Medicine in the 16-19 Centuries]*, Moscow, 1996, pp. 129-30; and V. O. Samoilov, *Istoriia Rossiiskoi Meditsiny*, Moscow, 1997, pp. 40-7, 61-73

[189] On the history of the medical faculty of Moscow University, see the most recent and full account in A. M. Stochek and S. N. Zatravkin, *Meditsinskii fakultet Moskovskogo universiteta v XVIII veke [The Medical Faculty of Moscow University in the 18-th Century]*, Moscow, 1996, pp. 9-49. On the reforms of education during the rein of Alexander I, see A. M. Stochek, M. A. Paltsev, S. N. Zatravkin, *Meditsinskii fakultet Moskovskogo universiteta v reformakh prosveshcheniia pervoi treti 19 veka [The Medical Faculty of Moscow University in the Reforms of Education in the First Quarter of the 19th Century]*, Moscow, 1998

[190] V. V. Kalnin, "Meditsina v Tartuskom universitete v 17-18 vekakh"["Medicine in the University of Tartu"], in *Iz istorii meditsiny [From the History of Medicine]*, Riga, 1983, pp. 20-32

[191] L. I. Mateunas, *200 let meditsinskomu fakultetu Vil'niusskogo universiteta im. V. Kapsukasa [Two Hundred Years of the Medical Faculty of Vilnius University after V. Kapsukas]*, Vilnius, 1981

achievement.[192] In the short period of its existence, the Dorpat University's Institute of Professors prepared six Doctors of Medicine, N. I. Pirogov among them. However, the critical state of Russian universities during the last decades of Nicholas I's reign was responsible for an inadequacy of medical teaching, a lack of modern Western medical literature, and a total absence of modern research facilities at the medical faculties of the universities, which could not compete with the Medico-Surgical Academy at the time of its ascendancy after the Crimean War.

The Crimean war had a profound and long-lasting impact on the development of Russia's social and economic resources. To quote one of Russia's diplomatic circulars to Europe after the Crimea, "...Russia is collecting her strength."[193] That meant, first and foremost, the modernization and reformation of all institutions of society: military, economic and educational, governmental, juridical, and social. The military strength of Russia would now depend on industrialization that in turn necessitated the development of a network of modern research and educational institutions, where science could serve military and economic objectives.

One of the most drastic aftermaths of the Crimean debacle was the acknowledgement of the disastrous situation in military medical administration, and the complete absence of communication lines that connected the army and its hospitals with the war supplies. The horrifying state of the military hospitals in Sevastopol showed all the deficiencies in Russian economic and administrative structure. Summarizing his

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[192] Here taught professor of surgery Johann Christian Moier (1786-1858) who had studied at the University of Pavia under Antonio Scarpa (1747-1832), eminent anatomists and surgeon. Moier worked in the leading clinics of Berlin and Vienna. According to Pirogov, Moier was a distinguished pianist, and a close friend of Beethoven. See, N. I. Pirogov, *Questions of Life*, pp. 278-9

[193] W. Baumgart, *Peace of Paris 1856. Studies in War, Diplomacy, and Peacemaking*, Oxford, 1981, p. 201

experience in the Crimean war, Pirogov put it as follows: "War is a traumatic epidemic. The priority in the treatment of patients in war should not be assigned to medicine, nor to surgery, but to an efficient administration."[194] The selfless work of Russian physicians and medical personnel alone could not save the desperate situation and improve the delivery of medical services in war. In a letter to his wife from Sevastopol in November of 1854, Pirogov wrote: "The battle of Inkerman cost the Russians 11,000 dead, and over 6,000 wounded. I found over 2000 wounded huddled in filthy quilts soaked in blood. We worked for ten days to sort them and separate those who needed urgent operations." In yet another letter from December of 1854 he reported that the sick were badly treated; the transport was abysmal and the wounded were transported in open carts. They lacked warm clothes, and yet they spent nights in the fields or in unheated peasants' huts.[195]

The hell and heroism of the Crimean war were best related in *Sevastopol'skie rasskazy* written in 1855 by Leo Tolstoy, who served as an artillery officer for eleven months in the besieged city. His depiction of the military hospitals in Sevastopol in terms faithful to the actual experience of men awaiting dreadful sufferings before amputation became a portrayal of the war as it is, in blood, sufferings, and in death:

> Now if your nerves are strong, go through the door on the left: in this room dressing and operations are performed. You will see doctors with their arms blood-stained to the elbows and their faces pale and gloomy, acting at the bed on which a wounded man is lying under chloroform with open eyes as in delirium, saying meaningless. sometimes simple and touching words. The doctors are doing the disgusting but beneficial work of amputation. You will see how a sharp curved knife pierces the

[194] N. I. Pirogov, *Sevastopol'skie pis'ma i vospominaniia [Sevastopol Letters and Reminiscences]*, Moscow, 1950, pp. 28-30. Apparently, some of these letters were written in hope that the Grand Duchess Elena Pavlovna, who was a close friend of Pirogov's second wife, would read them and could change the situation.
[195] *ibid*, p. 35

white healthy body; you will see how suddenly the wounded man comes to himself with a horrible, heart-rending cry and curses; you will see how a feldscher throws the cut arm into the corner; you will see how another wounded man who lies on a stretcher in the same room, looking at the operation on his comrade, and writhes and moans not from the physical pain but from moral sufferings of expectation, you will see awful soul-shaking scenes; you will see the war not as a splendid array of troops in accurate formation, with music and beating the drums, flying standards and prancing generals but war in its true expression, in blood, sufferings and death.[196]

Poor medical arrangements, insufficient preparations for the proper care of the sick and wounded, especially for the commonest surgical operations, lack of surgeons, dressers, and experienced nurses, constant want for the commonest appliances of a workhouse sick-ward and other urgent supplies (such as lint) became universal at the military hospitals in Sevastopol, Constantinople, Scutari, and Balaclava.[197] The British army in the East suffered severely from diarrhea and dysentery and a full-scale cholera epidemic; it was experiencing the same desperate situation as the Russians in Sevastopol. The dispatches from the battlefield published in *The Times* in October, 1854 were shocking: "Our victory has been glorious... but there has been a great want of proper medical attention. ...The number of lives which has been sacrificed by the want of proper arrangements and neglect must be considerable. ... Here the French are greatly our superiors. Their arrangements are extremely good, their surgeons more numerous, and they have also the help of the sisters of Charity who have accompanied the

[196] L. N. Tolstoi, "Sevastopol' v dekabre mesiatse," *Povesti i rasskazy*, 2 vols, Moscow, 1966, v. 1, p. 64

[197] On the hospital administration of the British, French, and Russian armies, much has been written on Florence Nightingale, the most recent is S. Goldie. ed, *Florence Nightingale. Letters from the Crimea 1854-1856*, Manchester, 1997. See also J. Shepherd, *The Crimean Doctors. A History of the British Medical Services in the Crimean War*, 2 vol., Liverpool, 1991. For the French side, there is, apart from contemporary and nineteenth century studies, no equivalent modern research. The same applies to the Russian side, cf. J. S. Curtiss, *Russia's Crimean War*, ... pp. 461-71. The classical account of the siege of Sevestopol by the chief Russian engineer Eduard I. Totleleben, *Opisanie oborony goroda Sevastopolia*, 2 vols, St. Petersburg, 1863-74 has an appendix about Russian hospital organization, translated into French: Eduard I. Totleben, *Service sanitaire des hôpitaux russes pendant la guerre de Crimée, dans les années 1854-1856*, St. Petersburg, 1870

expedition in incredible numbers."[198] Florence Nightingale's letters in which she mentioned Russian losses and Russian wounded are of interest, as they reflect the impressions of a nurse who was working in the wards in the British hospitals in the East for more then twelve hours a day in the most harrowing conditions while at the same time engaged in a struggle with officials to try and reduce the vast chaos of the hospitals: "...the mortality of the operations is frightful. We have Erysipelas, Fever and Gangrene. Russian wounded are the worst. It appears certain that she [Russia] has been drained every man she can afford. It is thought that the estimate of 500,000 losses is not at all too large. She was losing 3000 men per day at the time of the bombardment."[199]

That was even more tragic since epidemics caused even more deaths than did actual fighting. In the siege of Sevastopol alone the Russian army lost in sickness more than 183,000 men as compared with the losses in casualties and wounded about 128,669. French total loses reached 95,000, of these 20,000 died in action or from wounds received in action; the remaining, 75,000 is accounted for by deaths from sickness. British loses given by Lord Panmure, Secretary of State for War in 1856 were 20,000; out of these 4,000 were killed in action.[200] The Crimean war, in the words of Pirogov, was "a military trauma for all participants and a national calamity for Russia."

Those devastating statistics apparently influenced the far-reaching reforms in the St. Petersburg Medico-Surgical Academy. In 1857 Alexander II and War Ministry Count N. O. Sukhozanet committed the Conference of the St. Petersburg Medico-Surgical Academy to work out new regulations " in order to put medical science in

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[198] Godie, ed, *Florence Nightigale*, pp. 17, 18
[199] *Ibid*, p. 38
[200] Baumgart, *The Crimean War*, pp. 215-17. For Russia see also L. G. Beskrovny, *The Russian Army and Fleet in the Nineteenth Century. Handbook of Armaments. Personnel and Policy*, Gulf Breeze, Fla., 1996, p. 51; on the industrialization of war (the Crimean campaign) see G. Parker, ed, *Cambridge Illustrated History. Warfare*, Cambridge, UK, 1995, pp. 216-20

Russia on the same ground of perfection as in France and Germany."[201] In the official correspondence between the new War Minister Milutin and President of the Academy P. A. Dubovitskii (1815-68), namely in the report, "On the Necessity of the Reformation of the Medico-Surgical Academy," we find the reference to the leading European military medical schools: the Val de Grâce in Paris, the Chatham Army Hospital in England, the Friedrich-Wilhelm-Institut in Prussia, and Joseph's Akademie or Josephinum in Austria.[202] All of these institutions, Dubovitskii stressed in his report, were specializing in education for military doctors and remained under the authority of Ministry of War. The first two to be mentioned belonged to France and Britain, Russia's belligerents in the Crimea, followed by two Academies in Austria and in Germany that traditionally was the model for Russia in military matters.

Let us have a quick glance at the pillars of military medical education in Europe in those times. The Hôpital Val de Grâce, formally a monastery founded by Anna of Austria in 1645, became a large military hospital in 1793. From 1820 the chief physician there was the famous François Broussais (1772-1838), the inventor of 'physiological medicine' and the leader of Paris medicine for two decades in the 1820s and '30s. As Ackerknecht remarked, Broussais gathered around him a group of able young military physicians and surgeons who in the course of time filled leading positions in the French army's medical corps.[203] Like its French counterpart, the general hospital for the British

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[201] Glebov, *Kratkii obzor*, p. 4

[202] *Rossiiskii Gosudarstvennyi Voenno-istoricheskii Arkhiv [Russian State Archive for Military History]*, Moscow, fond 1, opis' 1, 1865, no 26984

[203] On Broussais at Val-de-Grâce, see Ackerknecht, *Medicine at the Paris Hospital*, pp. 62-4; and idem, "Broussais, or a Forgotten Medical Revolution," *Bull. Hist. Med.* (1953) 27: 320-43. On the general history of Val de Grâce, see J. Rieux and J. Hassenforder, *Histoire du Service de Santé Militaire et du Val de Grâce*, Paris, 1951. On the history of the growth of the epidemiological laboratory at Val de Grâce in the 1870s, see M. Osborne, "French Military Epidemiology and the Limits of the Laboratory," in Cunningham and Williams, eds, *The Laboratory Revolution in Medicine*, pp. 189-208

army at Chatham, near London, was not a specialized military medical school as in Austria and Prussia. However, as Muehry reported in his account of English military surgery, the hospital was under excellent regulation, with a good library, and a constantly increasing museum of anatomy and natural history. He further stated, that the monthly reports of the military surgeons were commonly expressed in conformity with the nosology of the famous Edinburgh clinician William Cullen (1710-1790). Muehry concluded that the English military surgeons had greatly distinguished themselves by their learning and by original works of geographical distribution of disease and zealous cultivation of natural history in foreign countries.[204]

Whereas in London and Paris, medical men educated elsewhere were attracted to military medical service by sufficient rewards and honour, in Vienna, Berlin and St. Petersburg there were specialized Military-Medical Academies founded circa 1790s. In Prussia the Pépinière, a school for royal medical officers within the Charité hospital in the 1820s was transformed into the Medizinisch-chirurgisches Friedrich-Wilhelms-Institut, while the Charité still remained its facility for clinical training. The Charité professors, notably Schönlein, Müller, Graffe, Rust, and Diefenbach had teaching responsibilities at the Institut and the medical faculty of Berlin University.[205] Another counterpart of the St. Petersburg Military-Medical Academy, the Austrian Josephinum was reopened in 1854, in large part as a reaction to the Crimean war. Emperor Francis Joseph realized that though Austria had managed to stay out of the war, it was the

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[204] A. Muehry, transl. E. D. Devis, *Observations on of the Comparative State of Medicine in France, England, and Germany, during a Journey into these Countries in the year of 1835*, Philadelphia, 1838, pp. 99-101

[205] D. Schickert, *Die Militärärztlichen Bildungsanstalten von der Gründung bis zur Gegenwart*, Berlin, 1895, pp. 18-20

country that had suffered most from its consequences.[206] Modernization of the Josephinum was directly associated with the setting up of a teaching and research laboratory of experimental physiology by Carl Ludwig in 1855. It marked the introduction of laboratory medicine to military-medical education and the growing prestige of experimental physiology.

The reformers of the St. Petersburg Medico-Surgical Academy understood that there was no need to create the same kind of institution in Russia *de novo*; rather it was possible to adapt the existing structures to the new demands. The reformers believed that no other educational institution in Russia and not many in Europe could boast of such favorable conditions and means for training physicians as the Academy: "Usually the specialized institutions are scattered at quite a distance from one another, for example, in Paris the syphilis hospital Hôtel du Nord from the typhus hospital Hôtel de St. Louis, the Pitié from the Hôpital Necker, and the Hôpital des Enfants Trouvés from Charenton. We have all hospitals and faculty clinics concentrated in one place within the territory of the Academy; in the hospitals there are lecture-rooms, laboratories, and libraries."[207]

It was crucial for the development of experimental sciences and scientific medicine at the Academy that its reorganization was pursued by "a triumvirate": President P. A. Dubovitskii, Vice President I. T. Glebov and Academic Secretary N. N. Zinin. In view of their accomplishments and social connections they comprised the unity of administrative experience, pedagogical talent, wide scientific outlook and an aspiration for modernization of the Academy.

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[206] Baumgart, *The Crimean War*, pp. 34-42

[207] Glebov, *Kratkii obzor*, p. 16. The same remark that the Paris hospitals are for the most part at a distance and far apart, as well as an account on their disposition, arrangement, and the staff of professors, is found in Muehry, *Observations*, pp. 17-23; see also Ackerknecht, *Medicine at the Paris hospitals*, pp. 15-25

Professor of surgery Petr Aleksandrovich Dubovitskii was a corresponding member of the Parisian Academy of Medicine (1846), an authoritative scholar (he had fifty published works) and a skillful surgeon, though his career as a surgeon had been interrupted by a tragic trauma of the hand.[208] He was a wealthy and influential member of St. Petersburg high society. Accepting the presidency of the Academy in 1857, Dubovitskii laid down a number of conditions that proved to be important in his reformist administration: the direct submission of the Academy to the War Minister and the abolition of the post of Trustee, so that he himself was the only intermediary between the Academy and Tsar and War Ministry.[209] The Conference of the Academy, a council of professors, was to exercise control of the Academy.

Dubovitskii threw himself tirelessly into concerns over external order and administration of the vast institution entrusted to him. A "passionate lover of building," in Sechenov's words, he worried day and night about putting up new buildings for housing teaching and research facilities.[210] According to the historian of the Academy, the vast territory occupied by the Academy had been neglected since the time of its foundation at the end of the eighteenth century. Situated on the banks of the Neva and Bol'shaia Nevka rivers it was in some places swampy and had only two groups of stone buildings. By the late 1850s, all the old wooden buildings had been torn down and the territory became a well-planned neat park with shady alleys, numerous flowerbeds and

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[208] Iu. L. Shevchenko, ed., *Professora Voenno-Meditsinskoi (Medical Surgical) Akademii (1798-1998) [Professors of the Military-Medical (Medical Surgical) Academy (1798-1998)]*, St. Petersburg, 1998, p. 12

[209] Usually the Trustee [popechitel'] executed the governing duties over the institution that was entrusted to him. He reported annually to the Tsar and to the responsible Ministry. N. I. Pirogov pointed to the dependence of the Russian universities on the institution of trustees: "Dorpat University had attained unprecedented heights, particularly under the trusteeship of Prince Liven, in the same time other Russian universities had gradually deteriorated due to the obscurantism and backwardness of various trustees." Pirogov, *Questions of Life*, p. 278

[210] Sechenov, *Autobiographical Notes*, p. 100

ponds. The times of Dubovitskii represented "the most glorious and flourishing period in the history of the Academy." It was marked by the spacious new buildings of the Mikhailovskii (Vil'e[211]) clinic, of the Natural History Institute, and of the Anatomico-Physiological Institute and of the Botanical Institute.[212]

The 'building campaign' required a great deal of investments, and Dubovitskii succeeded in persuading War Ministry that with the new Anatomo-physiological institute, the Museum for Natural History, and the chemical and physical laboratories, the Academy would rank among the best institutions of Europe. Apart from governmental support private funds were also donated to the wealth of the Academy. The documents reveal that a 'special income' of the Academy included an interest from the capital endowed to the Academy by the former War Minister N. O. Sukhozanet (1856-61) and by the President of the Academy Dubovitskii.[213]

The appointment of a new War Minister, Count D. A. Milutin ((1816-1912) in 1861 brought new support for the development of science-based medicine at the Academy. Milutin was a man of culture, with an extremely wide range of knowledge: he had published a number of works on mathematical and military subjects, the most famous of which was on A. V. Suvorov's 1799 campaign. His brother, N. A. Milutin, was one of the authors of the peasant reform of 1861. Milutin and his close associates in

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[211] Baronet Iakov Vasil'evich Vil'e (James Willie, 1768-1854) came to Russia as a physician to Prince Golitsin in 1790. Vil'e had studied medicine in Edinburgh and in 1794 got medical degree at the University of Aberdeen. He became a well-known surgeon, scientist and high rank military medical man in Russia. As a Chief Medical Inspector of the Russian Army and an acting surgeon, Vil'e took part in more then 50 battles during the Napoleonic wars and in Russian-Turkish campaign (1827-1829). Vil'e was the President of the St. Petersburg Medico-Surgical Academy (1808-1838), published a number of scholarly works (field surgery, pharmacopoeia, "dangerous diseases," cholera, plague) and initiated publishing of *Voenno-meditsinskii zhurnal [Military-Medical Journal]* (from 1823 till now). Part of Vil'e's considerable fortune was left by will to build a hospital, and part, to the tsar. Mirskii, *Meditsina Rossii*. pp. 188-97

[212] Ivanovskii, ed, *Istoriia Imperatorskoi Voenno-meditsinskoi Akademii*, pp. 524-45

[213] *Voennoe Ministerstvo, Smeta na 1866 god po Imperatoskoi S.-Peterburgskoi Med.- khirurgicheskoi Akademii [War Ministry, Estimate of the Expenses on the Imperial St. Petersburg Medico-Surgical Academy]*, St. Petersburg, 1867, p. 30

an 'enlightened' high bureaucracy insisted that the reforms must be produced only by the autocratic power aided by progressive and able advisers, who could rise beyond the outdated privileges of the Russian nobility for the welfare of the Empire. The author of the military reform of 1861-1874, Milutin wanted to profit by the example of the Prussian army. Bringing military reform to a successful conclusion was a result of the energy and perseverance of Milutin and the trust that Alexander II reposed in him.[214]

Milutin understood the necessity of giving officers a decent education as well as a thorough professional training. He fostered improvements in the system of military education to provide Russia with a new nucleus of officers who got scientific training adapted to the various specialties of the army. One of his main concerns was the modernization of military medicine and its institutions. Milutin expressed the attitude widespread among Russian liberal state ministers and academics that science-based education was essential for the economic and military strength of Russia. Reorganization of the Medico-Surgical Academy in the 1860s was part of a broader process of social and economic change defined by the Reform era and the pressure of nascent industrialization in Russia.[215]

In his survey of the history of the Academy, the pathophysiologist V. V. Pashutin, who was Head of the Academy in the 1890s, noted: "Dubovitskii was in every possible way supported by War Minister D. A. Milutin, who executed the immediate

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[214] Milutin, War Minister (1861-1881), General-Field Marshal (1898), Corresponding (1853) and Honorary (1866) member of the St. Petersburg Academy of Sciences, professor of the Military Academy; on his views on the reforms and the basic principles of Russia's inner and foreign politics, see D. A. Milutin, *Dnevnik [Diary]* with P. A. Zaionchkovskii "Biographicheskii ocherk" ["Biographical Essay"], Moscow, 1947; see also D. A. Milutin, *Vospominaniia general-feldmarshala grafa D. A. Milutina [The Recollections of General Field Marshall Count D. A. Milutin]*, 3 vols, with L. Zakharova, "D. A. Milutin, ego vremia i ego memuary" ["D. A. Milutin, his Time and his Memoirs"], Moscow, 1997

[215] On Milutin and the military reform see also P. Miliukov and L. Eisenmann, *Reforms, Reaction, Revolutions*, New York, 1969, pp. 45-7, and N. Riasanovsky, *A History of Russia*, New York-Oxford, 2000, pp. 374-8

will of the Tsar. For ten years, he reformed the Academy in all aspects and put it on the level of the best European educational institutions." Pashutin emphasized that the great triumph of 'scientific positivism' was inextricably connected with the "great revolution in the teaching of medical sciences. Natural sciences became the basis of medical education. A purely speculative orientation was replaced by the application of exact physical and chemical methods to the study of biological phenomena. Medical schools should have laboratories in which students can learn these methods."[216]

The significance of the natural sciences in medical education was best understood by professor of chemistry Nikolai Nikolaevich Zinin (1812-1880) who represented 'hard science' in the triumvirate. Dubovitskii highly valued Zinin as a scholar from the times when both taught at Kazan University: the former, surgery at the medical faculty and the latter, chemistry at the physico-mathematical faculty. Kazan University owed its notable reputation in chemistry due to the talents of Carl Clauss and Nikolai Zinin and their excellent chemical laboratory.[217] Zinin's successful research concerning aromatic compounds during his stay abroad in 1837-1840, particularly in Liebig's laboratory at Giessen, followed by his discovery of the reaction for the conversion of the aromatic nitro compounds into amines (aniline, naphthylamine, etc.) in 1842 gained him esteem among European organic chemists.[218] Zinin became one of the leading figures in the synthesis of organic compounds and his method for obtaining

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[216] V. V. Pashutin, *Kratkii ocherk Imperatorskoi Voenno-Meditsinskoi Akademii za 100 let eia syshchestvovaniia [A Brief Essay on the Imperial Military-Medical Academy: 100 years of its History]*, St. Petersburg, 1898, pp. 7, 19

[217] S. N. Vinigradov, "Chemistry at Kazan University in the Nineteenth Century: A Case of Intellectual Lineage," *Isis* (1965) 56: 168-73

[218] N. Zinin, "Organische Salzbasen aus Nitronaphthalos und Nitrobenzid mittelst Schwefelwasserstoff entstehend," *Annalen der Chemie und Pharmacie* (1842) 44: 283-287. On Zinin's researches on aromatic compounds see, Partington, *History of Chemistry*, v. 4, pp. 330, 435, 561; for Zinin's original works and

cheap aniline laid the foundation for the dye industry in Russia.

In 1848 Zinin was appointed professor of chemistry to the Medico-Surgical Academy. Unlike his predecessors he took upon himself the chemistry course only; physics was assigned to an adjunct. He made some improvements in the curriculum: the course of inorganic and analytical chemistry was shifted to the first year whereas organic chemistry with its application to physiology was given in the second year. Zinin favoured the Liebigian model of chemical practicum, which exploited a set of apparatus and techniques, which Liebig had invented, including his famous Kaliapparat method, for teaching organic analysis.[219] Zinin understood that to ensure its relevance to medical practice, laboratory training in chemical diagnostic procedures and in quantitative chemistry should be available for students. Although Zinin was training selected students in his private laboratory at the Academy, the resources and facilities needed for practical training of ordinary medical students were far beyond what he could afford. Borodin reported in 1862:

> Conditions in the Department of Chemistry were at that time in a very sad state. Thirty rubles a year were appropriated to chemistry, with a fight to ask as much again during the course of the year. This was the time when it was sometimes impossible to find a test tube in St. Petersburg, and when you yourself had to make rubber connections, etc. The academy laboratory offered two dirty, gloomy rooms with arches, stone floors, several tables, and empty cupboards. Because of the lack of hoods, the distillations, evaporations, etc. had to be performed outside, even in winter. Organized practical work was out of the

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bibliography see, N. A. Figurovskii and Iu. I. Solov'ev, *N. N. Zinin. Biographicheskii ocherk*, Moscow, 1957

[219] The most recent biography of Liebig is W. H. Brock, *Justus von Liebig: The Chemical Gatekeeper*, Cambridge, 1997; on Liebig and his research school, see F. L. Holmes, "Complementarity of Teaching and Research in Liebig's Laboratory," *Osiris* (1989) 5: 121-64; on the birth of the teaching and research laboratory see T. H. Levere, *Transforming Matter A History of Chemistry from Alchemy to the Buckyball*, Baltimore, 2001, pp. 121-35; the most recent and interesting account on the use of Liebig's potash apparatus, see A. J. Rocke, "Organic Analysis in Comparative Perspective: Liebig, Dumas, and Berzelius, 1811-1837," in Holmes and Levere, eds, *Apparatus and Experimentation in the History of Chemistry*, pp. 273-310

> question. But even under these conditions Zinin always found a love for work. Five or six fellows always worked, partly on their own and partly under Zinin's personal supervision. This situation continued until the beginning of the 1860s.[220]

However, as Borodin recalled, Zinin's laboratory at the Academy in the late 1850s was like "a miniature chemical club, an improvised session of the Chemical Society where the life of Russian chemistry bubbled up."[221]

The issues concerning the expansion of the laboratories for organic chemistry and physics received satisfactory resolution in 1863 with the opening of the Natural History Institute. Zinin succeeded in obtaining an appropriation for 45,000 roubles for the interior arrangement and equipment of the chemical laboratory and a yearly grant of 2000 roubles for apparatus and reagents. Concerned to provide additional support for improvements in teaching natural sciences at the Academy, Zinin insisted that separate chairs of chemistry, physics, comparative anatomy, and botany must be established.[222]

In 1862 after studies abroad, Zinin's best student Borodin was elected adjunct. As Zinin's principle co-worker, he had to take upon himself a great deal of work connected first with construction and then with the equipment of the laboratory in the new building of the Natural Science History Institute. In the letter to his fiancée Protopopova, Borodin reported: "I wrote and calculated all week. This work consisted of an order of laboratory things from abroad, which will be fairly advantageous. Now each student will receive a full set of chemical cups and glasses, etc., and beyond that, more than 1000 rubles are left of the money with which many good instruments for the

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[220] B. N. Menshutkin, *Nikolai Nikolaevich Zinin. Ego zhizn' i nauchnaia deiatel'nost' [N. N. Zinin. His Life and Scientific Activity]*, Berlin, 1921, pp. 58-9 [in Russian]

[221] A. P. Borodin and A. M. Butlerov, "N. N. Zinin. Vospominaniia o nem i biograficheskii ocherk" ["N. N. Zinin. Reminiscences and Biographical Essay"], *Zapiski Akademii nauk [Proceedings of the Academy of Sciences]* (1880) 37(1): 1-46

[222] *Rossiiskii Gosudarstvennyi Voenno-istoricheskii Arkhiv*. Moscow, fond 316, 1863, opis' 46, delo 373

laboratory can be acquired."[223]

The principal difficulties Zinin was facing during the period of the organization of the work of the laboratory were reported by Borodin in his letter to Butlerov:

> I read organic chemistry (three lectures a week), and besides I was entrusted with participating in the organization of the laboratory. The [new] laboratory will be good but what can we do if we do not increase the staff? Day after day Zinin pleads with all his might, but it seems to be of no avail. They [the authorities] even cut down drastically the number of attendants. They left only three, and there are one hundred and four places in the laboratory. The number of workers will certainly reach fifty (this was the condition without which they would not agree to give us money for the laboratory). They will not agree to give us a special assistant, and it is impossible to manage without one. Although Zinin and I insist that one professor cannot lecture and conduct practicum, nothing comes out of it. ... About 2000 rubles a year is allowed for maintenance of the laboratory, besides we need money for the materials (acids, soda, potash, alcohol, etc.) from the chemist's shop. There is very little for a large number of occupants, for it is impossible to deduct anything for broken dishes and materials. The students have nothing, they do not pay for the laboratory, and do not receive a salary... It is impossible to impose on the students the obligation of any fee, for even without this, they pay 50 rubles a year to the Academy. All this greatly implicates future work in the laboratory and causes a somewhat unpleasant feeling which was already evident belief. That it is impossible to conduct work in the manner one would like. But in the future perhaps the higher authorities will be convinced that our demands were completely well grounded.[224]

Zinin was well acquainted with the system of chemical education promoted by Liebig and carried on at Heidelberg University by Bunsen. Crucial for the entire program of improving chemical education was the simultaneous development of disciplines regarded as auxiliary to chemistry such as physiology and physics. Shaping a program for chemical instruction at the Academy, Zinin had to adjust it to the needs of a

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[223] Borodin to Protopopova, letter, d. Heidelberg, September 1862, in Dianin. *Pis'ma Borodina*, p. 56
[224] Borodin to Butlerov, letter, d. St. Petersburg, 15 July 1863, cited in Figurovskii and Solov'ev, *Borodin*, pp. 49-51

medical institution. Motivated by concerns to reform medical education, he saw clearly the great advantage in incorporating a practicum in chemistry into the medical curriculum, and criticized the role of natural sciences in the present curriculum of the Academy:

> ...medicine, like science, represents only an application of natural science to the problem of the preservation and restoration of health. Natural science therefore must play a most important role in medical education but by no means must it be a supplementary and an auxiliary aid. The physician needs to master general systems of science, the method of thinking, and devices and methods of investigation rather then many fragmentary facts of applied natural sciences. Therefore the teaching of natural sciences in the Academy must be basic and necessarily full, not restricted to the cramped limits of applied knowledge. And for sound learning and a true evaluation of what has been done in science by others, for a clear knowledge of which path science grows by and [how] scientific data are cultivated and increased, it is necessary for each student to work directly and independently at something, according to his specialty, in some branch of natural science. Only physics and chemistry hold the key to the explanation of all those complex and infinitely different physiological and pathological processes which occur in an organism.[225]

Motivated by Zinin's reputation as a popular teacher, who had promoted and developed a program of teaching and research at Kazan University (1842-47), Dubovitskii entrusted to him the task of renewing the staff of professors at the Academy. Zinin considered physiology central among the medical disciplines, and proposed that the physiologist Ivan Timofeevich Glebov (1806-1884) be appointed Vice-President of the Academy. They had been close friends from the time when both had studied abroad. Before his appointment to the Academy, Glebov had taught comparative anatomy and physiology at Moscow University. At the Academy, he became Dubovitskii's right hand in the organizational matters. Glebov was the right person to shape a program of reforms

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[225] Ivanovskii, ed., *Istoriia Imperatorskoi Voenno-Meditsinskoi Akademii*, p. 529

at the Academy according to the governmental efforts and concerns to upgrade the professorial and research standards in medical education. He was commissioned to visit a number of clinics, anatomical and physiological institutes throughout France, Germany, England, Scotland and Austria, and, guided by the achievements of Western medicine, worked out a detailed plan for the reformation of the Academy, outlined in his *A Brief Survey of the Activities on the Improvement of the Imperial Medical Surgical Academy.*[226]

In Western Europe during the nineteenth century, as demonstrated by Coleman and Holmes, experimental physiological investigation, had become intense and continuous within institutional settings specially structured for that purpose. By 1850, laboratories were creating a new physiology and pathology and beginning to reshape medical education. Many European universities already in the mid 1850s began constructing new research institutes equipped with laboratories intended specifically for student instruction. [227]

A detailed analysis of the War Ministry Archives reveals the primary determinant in the decisions of the Conference of the Academy to have been the immediate needs of the state in raising the level of training of physicians based on the ideas of scientific medicine. The statute "On the Founding of the Anatomico-Physiological Institute" stressed: "The objective of the Institute is to give the students the means for practical studies in anatomy and independent research in the following fields: comparative anatomy, physiological anatomy, and experimental physiology. ... [It will] favour the training of the future lecturers in anatomy and physiology not only

[226] Glebov, *Kratkii obzor deistvi Imperatorskoi Meditsinsko- Khirurgicheskoi Akademii*
[227] W. Coleman and F. L. Holmes, "Introduction," in Coleman and Holmes, eds. *The Investigative Enterprise*, p. 4

for the Academy but for other medical educational institutions of Russia."[228]

The statute defined primary expenses for setting up a new institute:[229]

	Roubles
Building alterations:	249
Room w. stove for small animals	501
Maceration room w. basement	784
Chapel	469
1 microscope, large	228
Anatomical & chemical instruments	285
Total	2,519
Annual expenses of Institute (1859)	4,428

The Conference acknowledged that medicine would profit from a greater emphasis on experimental physiology and laboratory training.

> Teaching experimental physiology, i. e. demonstrating experiments and conducting research, that lead to understanding and discovering of the laws of organic life, has been introduced in all medical educational institutions abroad. There is no doubt that teaching experimental physiology is one of the most fruitful ways to develop science and at the same time it is a necessity for the training of physicians.[230]

Improvement of the Academy's natural science departments was another pressing concern for the Conference. The new statutes of the Academy stressed the importance of natural sciences in the curriculum: "All phenomena and processes that take place in nature are of the same kind as those in the human body. And the bodily processes in miniature follow the same mechanical (physical) and chemical laws as in

[228] *Rossk. Gos. Voen.-Ist. Arkhiv*, Moscow, fond 1, opis' 1, 1859, no 24527
[229] *ibid.*
[230] "Proceedings of the Conference of the Academy," 26 March 1860, in Koshtoyants et al, eds, *Nauchnoe nasledstvo, I. M. Sechenov. Neopublikovannye raboty, perepiska i dokumenty [Scientific Heritage. I. M. Sechenov. Unpublished Works, Correspondence and Documents]*, Moscow, 1956, p. 25

nature. … Here is the link between medicine as a science of human beings and the natural sciences. Therefore natural sciences are fundamental and not auxiliary in teaching medicine." Physics, chemistry and natural history came to be seen as the basis for medical education: "Natural sciences are to be equal in their importance with medical subjects, the scope of their teaching is to be wider and fuller, the way of teaching is to be not only theoretical but also practical."[231] The Conference requested that 5185 roubles be provided by the War Ministry for the arrangement of five new departments:

> The Conference of the Imperial Medico-Surgical Academy considers its main duty to find all possible means for improving teaching the sciences in the Academy. It therefore decides to increase the number of medical chairs and departments of natural sciences and a number of teachers in order to make the training more practical and rational. These are: 1. Natural sciences: physics, meteorology, climatology, and physical geography; 2. Botany; 3. Nervous and mental diseases; 4. Practical anatomy; 5. Ophthalmologic diseases.[232]

Yet another important issue for the Conference was the work of renewing the staff of professors. Zinin had prepared the chemist Borodin and the physicist P. P. Khebnikov, for teaching at the Academy, and he evidently entrusted the task to Glebov who knew well the medical establishment in Moscow. It was through Glebov that Sechenov, Botkin, Bekkers, and Junge got a call to the Academy in 1860. Given the significance of experimental physiology as a discipline in the medical curriculum, Sechenov's appointment was celebrated in the proceedings of the Conference in March, 26 1860: "… with the appointment of I. M. Sechenov to the chair of physiology it becomes possible to raise the level of teaching to European standards and also to give

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[231] Glebov, *Kratkii obzor*, pp. 6-7
[232] *Rossk Gos. Voen.-ist. Arkhiv*, Moscow, fond 1, opis' 1, 1860, no 24894

impetus to the development of physiology in our country."[233]

The establishment of a new system of training of qualified lecturers at the Academy was of crucial importance in the rise of the advanced experimental sciences in Russia and in the emergence and growth of a national medical and research elite which was intellectually and institutionally connected with the European scientific community. In 1858 Tsar Alexander II approved the project on the foundation of the Institute of Physicians, presented by Dubovitskii. It stated:

> the best ten physicians after graduating from the Academy are to be kept on for further studies (they should be affiliated to the II Military Land Forces Hospital) for another three years. During this period they are to choose a department and a supervisor for their research work and by the end of the third year to submit their theses for defense. The best three Doctors of Medicine are to be sent abroad for two years in order to perfect their research and teaching skills in the best West European medical institutions and laboratories. The Conference of the Academy is ordered to have of such candidates thirty in number at the Academy and six abroad.[234]

Glebov, curator of the newly established institute, wrote: "Owing to the Institute of Physicians, the exciting achievements in the development of modern sciences will disseminate and grow in our Academy. Scientific knowledge will be spread on a constant basis not only at the Academy, but among medical communities throughout Russia. And as we hope, the achievements of scientific medicine will become established in our country and that will lead to the independent development of Russian science."[235] Five years later Glebov commented on the research works of the first graduates of the Institute:

> ... routine and compilation have been left behind; research work has been based on the

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[233] Koshtoyants et al, eds, *Nauchnoe nasledstvo*, pp. 25-6
[234] *Rossk. Gos. Voen.-ist. Arkhiv*, Moscow, fond 879, opis' 1-4, 1861, no 1062
[235] Glebov, *Kratkii obzor*, p. 33

knowledge of physics and chemistry and has become more independent and original. But that is not all: the principles of scientific medicine have been wide spread among the undergraduates of the Academy. Of great importance is that the principles of rational scientific medicine based on natural sciences has been introduced into our clinics and has been adopted by practical medicine.[236]

The Institute of Physicians was able to cultivate a core of productive, elite national cadres. According to Borodin, "the Institute of Physicians accomplished on its own the achievement of becoming a breeding ground of Russian scholars and an educational strength not only in the field of medicine but partly also in natural science. In the course of twenty years it gave Russia 129 young public figures, of whom 58 devoted themselves to professorial activity at academies and universities; the rest distinguished themselves more or less prominently by activities in the field of medical science, either practical or administrative."[237] The most distinguished graduates of the Institute were the professors of the Academy pathologist V. V. Pashutin, physiologist I. P. Pavlov, and neurologist V. M. Bekhterev (1857-1927).

The War Ministry set out to make the Academy a center for medical instruction in the Empire. The annual financial accounts of the Academy show a stable increase in overall expenditures throughout a decade from 1857 to 1870 (151,874 roubles in 1864, and 57,000 roubles more in 1866). However, the expenditures devoted to the special institutions such as the physiological laboratory remained the same.[238] "The estimate of the expenses of the War Ministry on the Imperial St. Petersburg Medico-Surgical Academy," demonstrates the assessment of the means of such a huge and complicated

[236] Ivanovskii, ed, *Istoriia Imperatorskoi Voenno-Meditsinskoi Akademii*, p. 540
[237] Borodin's Speech Delivered on February 9, 1880 at Zinin's funeral, cited in Figurovskii and Solov'ev, *Borodin*, p. 150
[238] *Rossk. Gos. Voen.-ist. Arkhiv*, Moscow, fond 316, opis' 60, 1864, no 271

medical and scientific enterprise as the Academy: [239]

	Roubles
Maintenance costs of the Academy:	208,526
Maintenance costs on the scientific institutions:	28,837
Libraries (purchasing books, subscription to the foreign scientific journals, etc.)	6,000
Physiological and anatomical courses	700
Research travels abroad (for physicians preparing for a teaching career at the Academy)	7,200
Publishing of the scientific works of professors and lecturers of the Academy	1,401
Funding for graduates studying abroad	2,333

In ten years (1860-1870), that were rightly called the "golden age" of the Academy, it was transformed into a medical institution with physiological and chemical and clinical laboratories, and a specialized teaching clinic, a center for scientific medicine and advanced experimental inquiry. Having examined the institutional history of the Medico-Surgical Academy, I turn to discuss the emergence of the scientific teaching laboratory at the Academy, the major innovation introduced by the Russian institutional leaders, Botkin, Sechenov and Cyon, and how their pioneering practices influenced the development of laboratory medicine in Russia.

239 *Voennoe Ministerstvo, Smeta*, pp. 24-5

2. 'Scientific Medicine' at the Medico-Surgical Academy: S. P. Botkin

The shift in medical education from teaching theory to the use of exact methods in studying the natural processes in the organism was one of the consequences of the new direction in medicine with its demands for the practitioner to apply new diagnostic tools and to understand the results obtained by investigators. The development of new methods of 'scientific' medicine, the chemical tests, clinical thermometry and microscopic pathology, was the concern of the physiologist as well as of the clinician. As Arleen Tuchman points out, in Germany the introduction into the clinic of microscopical and chemical analysis, percussion and auscultation began to provide medical education with a practical emphasis. A new generation of students and the younger professors, skilled in these techniques, were demanding changes in clinical education.[240] In the late 1850s in Berlin University, among eighty medical courses and lectures only three of them were focused on laboratory training: one in physiology, one in pathological histology, and one in medical chemistry. However, these alone were promising to provide 'practical and scientific' instruction as well as instruction in conducting research in a laboratory.[241]

In Russia the introduction of scientific methods into clinical medicine started at the Medico-Surgical Academy with the appointment of Botkin in 1860. Botkin's idea of organizing a specialized laboratory for new diagnostic methods and research was supported by the Conference. Dubovitskii and Glebov acknowledged the need to provide new facilities for realization of Botkin's plan and requested that 1,471 roubles be

[240] Tuchmann, "From the Lecture to the Laboratory: the Institutionalization of Scientific Medicine at the University of Heidelberg," in Coleman and Holmes, eds, *The Investigative Enterprise*, p. 73

[241] H. H. Euler, *Die Entwiklung der medizinischen Spezialfächer an der Universitätendes deutsches Sprachgebietes*, Stuttgart, 1970, p. 89

released for the laboratory arrangement, and 600 roubles to purchase instruments and apparatus. These were: different kinds of weights (physiological, pharmaceutical, chemical) with necessary accessories; water bath, sand bath and air baths with thermometers; spirit lamps; drying apparatuses; equipment for urinalysis; air pump with brass plates and bell-glass; induction apparatus of du Bois Reymond with accessories; polarization apparatus; apparatus of Hoppe-Seyler for determining haemitin; dynamometer; insufflator; areometer;[242] different kinds of chemical glassware, porcelain crucible and cups for evaporation. An additional 900 roubles were spent on two microscopes, thermometers, batteries for strong currents and chemical materials and reagents. Everything was ordered and delivered from abroad, principally from Berlin and Paris.[243] Botkin managed to equip his laboratory in the same way as Hoppe-Seyler's laboratory at the Pathological Institute in Berlin. Botkin's vision of a clinical laboratory might also be well in accordance with Bernard's view that "the laboratory of a physiological physician must be most complicated of all laboratories, because the experimental analyses to be made there are the most complex of all, requiring the help of all other sciences."[244]

Unfortunately little is known about experiments which were carried out at the laboratory at that time, but from the list of instruments, it can be inferred, at least, that a standard set of methods and techniques to examine and test bodily fluids and tissues could be studied there: Hoppe-Seyler's device was used to obtain haematin by the

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242 An dynamometer is an apparatus for measuring power, esp. muscular effort of men or animals; an insufflator is a device for blowing air into lungs; an areometer [Gr. *araios* thin, rare + *-meter*] – a hydrometer, an instrument for measuring of density of fluids and solids.

243 *Ross. Gos. Voen.-ist. Arkhiv*, fond 316, opis' 31, delo 573, list 3 from Oct. 19, 1860

244 C. Bernard, *Introduction to the Study of Experimental Medicine*, H. C. Green, transl., L. J. Henderson, introduction, New York, 1958, p. 149

decomposition of haemoglobin for the purpose of demonstrating its crystalline form microscopically; a water-bath could be used for experiments on digestion, or for evaporating at a constant temperature for different purposes.

The work at the laboratory was organized in such a way that students could advance gradually from basic technique in laboratory tests of blood and urine and work with varied chemical reagents and animals to assigned research projects. Microscopic technique was also an essential part of the teaching program. First Botkin had to do everything by himself, as the young physicians who assisted him were not prepared for experimental work.[245] He saw clearly the deficit in the training of medical students in the use of exact physical and chemical methods in clinical research. Moreover, the students sometimes did not even know how to apply a thermometer on a patient. Therefore, in Botkin's opinion, the teaching clinic and the laboratory, uniting bedside experience and experimental investigation of the disease, were of particular importance for training physicians capable to use in their practice the results obtained by pathological anatomy, microscopy, and chemistry.

In the reports and accounts submitted to the President of the Academy, Botkin stressed the necessity of adequate funding for the arrangement of practical instruction of the students in the laboratory. The analysis of the financial accounts of the Academy to the War Ministry for 1860 –1862 shows that the new clinical laboratory was funded rather generously; all Botkin's requests supported by the Conference were fulfilled by War Ministry. Some funds were released by a special request of the tsar Alexander II himself: 3,000 roubles for instruments and materials to equip the clinical study-room of

[245] V. N. Sirotinin, "Biograficheskii ocherk" ["Biographical Essay"] in S. P. Botkin, *Kurs kliniliki vnutrennikh boleznei [Clinical Course on Internal Diseases]*, St. Petersburg, 1912, pp. 20, 25, 26

Botkin, surgical and ophtalmological study-rooms of Bekkers and Yunge.[246]

After a year's work, Botkin was promoted to professor ordinarius. However, though supported by the 'triumvirate,' his appointment met opposition from senior professors. According to Belogolovyi, the so-called 'German faction' among the members of the Conference insisted that one of the senior professors should head the clinic instead of Botkin. Clinical practice still consisted mainly of an empirical approach in diagnostics and therapeutics, and for the professors of old school the introduction of laboratory methods and experiments into the clinic meant a shift in medical practice from the bedside to the laboratory. These professors were reluctant to cede their clinical authority to the medical researcher. Botkin was well aware of their motives and was ready to resign. A deputation of students presented a petition in support of the young adjunct and that influenced the decision of the Conference in favour of Botkin.[247]

Botkin was interested in experimental research and spent much time in his laboratory. Virchow's idea that pathology should be based on a combination of clinical observation and experiment had made a great impact on Botkin. He shared Virchow's threefold approach to research on disease and cure, and for him the experiment appeared only as a means for studying clinical problems.

> The first is the clinic: examination of the sick with all the means of physics and chemistry under the principle direction of physiology and anatomy. The second is experiment: induction of the disease and investigation of the effect of drugs on animals. The third, finally, is microscopy: the study of the (dead) body and its isolated parts with the scalpel, microscope and reagents.[248]

[246] *Ross. Gos. Voenn.-ist. Arkhiv,* fond 316, list 4-5, 8
[247] Belogolovyi, *Botkin,* pp. 26-7
[248] K. Wenig, ed., *Rudolf Virchow und Emil du Bois-Reymond Briefe 1864-1894,* Marburg, 1995, p. 31

Although Virchow's influence on Botkin is undeniable, Botkin's clinical thinking was broader, as he proceeded from pathological changes as the base but not essence of the disease.[249] Botkin believed that a physician should not hold to cellular pathology alone; to explain disease, he had to proceed from the observation of a sick person and understand the essence of the disease by means of physiology, using all allied sciences. Physiological medicine implied non-specificity of disease: disease was seen as a deviation from normal values, ascertained through physiology. This widely accepted notion, associated with the introduction of laboratory-based methods of research, represented for Botkin the 'external side' of his reformation of the clinic, whereas clinical medicine itself formed the 'internal side.'

Botkin understood that limited therapeutic means and rare innovations in therapeutics, and the complexity and individuality of disease process to a great extent determined contemporary medicinal practice. Careful observation at the bedside, comparing similar cases that eventually led to generalized conclusions about the disease and its treatment were still at the core of clinical medicine. Pathological anatomy could provide evidence of the diseased organ or tissue and help in diagnoses in post mortem examination. Chemical analysis could help in diagnosing only certain conditions and could also be used for more accurate preparation of remedies. The possibilities for applying the results obtained through experimentation on animals as well as therapeutic evaluation of the efficacy of the remedies available for treatment were too limited.[250]

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[249] Botkin, *Kurs kliniki*, p. 4; see also N. F. Golubov, "O napravleniiakh v russkoi klinicheskoi meditsine" ["On the Trends in Russian Clinical Medicine"], in G. A. Zakhar'in, *Klinicheskie lektsii [Clinical Lectures]*, Moscow-Petersburg, 1894, p. 72

[250] E. H. Ackerknecht, *Therapie von den primitiven bis zum 20. Jahrhundert*, Stuttgart, 1970, pp. 95-121; see also P. Diepgen, *Geschichte der Medizin*, Berlin, 1951, 3 vols in 2, v. 2, pp. 163-166; a useful discussion on therapeutic reasoning in the mid-nineteenth century see in Weisz, *The Medical Mandarins*, pp. 159-67

However, the demand for physiological or 'scientific' medicine put experimental research at the center of the clinical laboratory; furthermore, the laboratory itself became a symbol of a new relation between medicine and science, which despite few observable gains was viewed as a powerful means in conquering the disease. The introduction of the laboratory into medical practice thus embodied the unification of theory and practice that were forced by the socio-economic changes in society.[251]

Botkin's commitment to 'scientific medicine,' which was associated with a general belief in the improvement of life and social progress made Botkin's lectures popular at the Academy. According to Belogolovyi, Botkin was considered one of the best lecturers among the clinical professors: his lectures were business-like discussions without unnecessary eloquence, sometimes with original improvisations, accompanied by carefully prepared demonstrations on patients. Disease in his lectures was presented not as an abstract entity but individualized with all changes and deviations in any specific case, and doing so Botkin taught how to treat the patient not the disease.[252]

Botkin published his *Clinical Course on Internal Diseases* in 1867,[253] and at the same time began to edit the *Archives for the Clinic of Internal Diseases by Professor Botkin*, the first specialized journal of its kind in Russia. Here in 1875, he published one of his best research works "On the Reflex Phenomena in the Skin Vessels and on Reflex Perspiration," which represented the synthesis of careful observations at the bedside, physiological knowledge and application of laboratory methods to the clinical

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[251] J. Bleker, "Die Idee der Einheit von Theorie und Praxis in der Medizin und ihr Einfluss auf den klinischen Unterricht im 19. Jahrhundert," *Arzt und Krankenhaus* (1982) 55: 232-236; see also Lenoir, "Laboratory, Medicine and Public Life in Germany 1830-1849," Cunningham and Williams, eds, *The Laboratory Revolution*, pp. 36-7; and Tuchman, "From the Lecture to the Laboratory," Coleman and Holmes, eds, *The Investigative Enterprise*, pp. 85-6
[252] Belogolovyi, *Botkin*, pp. 30-2
[253] S. P. Botkin, *Kurs kliniki vnutrennikh boleznei*, St. Petersburg, 1867

problem.[254]

Describing and interpreting various pathological conditions in his *Lectures* Botkin emphasized the traditional idea of the significance of the nervous system in the development of the disease process. That was the first principle of his clinical vision. Numerous investigations, related to the nervous system and physiology and pathology of organs of the body, were carried out in Botkin's laboratory by him and his students. I. P. Pavlov wrote in this respect: "I was surrounded by the clinical ideas of Professor Botkin and I acknowledged with a hearty gratitude a fruitful impact of Botkin's notion of nervism on my work and in the whole on my physiological views, which was deep and broad and frequently foreshadowed the experimental facts. In my opinion, that was a great service to physiology." [255]

Botkin viewed disease as a process spreading all over the organism and that was reflected in his studies of different clinical problems. He argued that the cause of catarrhal jaundice, for instance, was not a mucous plug in the common bile duct (Virchow's interpretation) and advanced a new interpretation of this disease as an infectious one (in Russia it is still called 'Botkin disease'). That was the second principle of his notion of clinical medicine. He felt that the anatomical approach was too narrow and one-sided, however he did not belittle its importance. In his lectures he gave a detailed analysis of the post mortem data and discussed their significance in pathology, diagnostics, and prognosis. Finally, the third principle was recognition of the importance

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[254] Published in Pletnev, *Russkie terapevticheskie shkoly*, pp. 75-86

[255] I. P. Pavlov "Sovremennoe ob"edinenie v eksperimente glavneishikh storon meditsiny na primere pishchevareniia." in *Trudy ob-va russkikh vrachei v S.-Peterburge za 1899-1900 gg. [Works of the Society of Russian Physicians in St. Petersburg for 1899-1900]*, (1900) 67: 197-242, cited in A. L. Miasnikov, "Vstupitel'naia lektsiia" ["Introductory Lecture"] in S. P. Botkin, *Kurs kliniki vnutrennikh boleznei [Clinical Course on Internal Diseases]*, Moscow-Leningrad, 1951, p. 4. Pavlov interpreted the notion of 'nervism' as "physiological trend aiming to extend the influence of the nervous system to the greatest possible number of the organism's functions," *ibid*, p. 5

of the environment in the development of the disease: "Our conception of the disease is closely connected with its cause which always conditioned by the environment, acting on the diseased organism either directly or indirectly."[256]

In Russian clinical medicine of the second half of the nineteenth century, despite the immense success of pathological anatomy, preference was given not to morphological but to traditional anatomo-physiological, functional trend. It was clearly reflected in the works of Botkin and other well- known Russian clinicians, such as Nikolai Sklifosovskii (1836-1904) and Alexander Ostroumov (1844-1908). The clinician Eikhvald wrote in 1871 in this respect: "It is necessary to take not an anatomical but a physiological viewpoint. The anatomical viewpoint as the basis of modern pathology gives medicine a somewhat gloomy character. From the anatomical viewpoint all the disorders of blood circulation are incurable... The physiological viewpoint is more consoling and no less important."[257] Experimental research, primarily of a physiological character, performed in clinical laboratories became a characteristic feature of the Russian therapeutical school.

We may catch a glimpse on Botkin's laboratory for animal experiments in pharmacology, through the eyes of Pavlov who managed the laboratory from 1878 to 1890:

> Despite something unfavourable that was in that laboratory, mainly, of course, scarcity of means, the time I spent there was very useful for my scientific career. Firstly, total independence and then a possibility of doing only laboratory work (I had no duties in the clinic). I worked there without discrimination between what is mine and what not. For months and years I spent my laboratory labors taking part in the works of others. However,

[256] S. P. Botkin, "Obshchie osnovy klinicheskoi meditsiny," ["General Principles in Clinical Medicine"] in Daily Clinical Paper (1886) 37: 732-735, cited in Miasnikov, "Vstupitel'naia lektsiia," p. 8
[257] E. E. Eikhvald, *Patogenez i semiotika rasstroistv krovoobrashcheniia [Pathogenesis and Semiotics of the Blood Circulation Ailments]*, St. Petersburg, 1871, pp. 8-9

there was always a personal advantage: I had more and more practice in physiological thinking in a wider sense and in laboratory technique. Moreover, I had always interesting and instructive (unfortunately extremely rare) discussions with Sergei Petrovich Botkin. Here I did my thesis on the nerves of the heart; and here after I had returned from abroad I began my work on digestion. Both projects I worked out independently.[258]

In his interesting and useful discussion on Pavlov at Botkin's laboratory, Daniel Todes points out that it was here that Pavlov discovered a talent and enthusiasm for running a laboratory and an opportunity to emulate the Heidenhein-Ludwig model, albeit with some important and frustrating limitations. Botkin rarely appeared at the laboratory as he held enormous responsibility for his clinical and private practice. However, he assigned dissertation topics to the one or two physician-investigators who arrived each year. Despite his private sentiments towards his work at Botkin's laboratory, Pavlov did appreciate Botkin's "magic" clinical abilities and his belief in the unique virtues of the laboratory.[259]

Botkin enjoyed a successful academic career at the Academy. He published about 75 works in various fields - therapy, infectious diseases, experimental pathology, and pharmacology. He was recognized as one of the founders of military field therapy in Russia, who adapted his teaching on internal diseases to military conditions. In his youth, he had been involved in the Crimean war, and he continued his practice as a military physician, spending seven months at the Balkan front during the Russo-Turkish war of 1877. Botkin, in contrast to his colleague and friend Sechenov, was involved in various public and philanthropic activities: the founder of the Courses for Women-Physicians and a free hospital in Moscow; Head of the Society of Russian Physicians,

[258] I. P. Pavlov, *Avtobiografiia [Autobiography]*, Tovarishcheskaia pamiatka vrachei vypuska 1879 g., izdannaia ko dniu 25-letiia so dnia okonchaniia kursa [Leaflet of the Alumni of 1879, printed on the 25 jubilee of graduation from the Academy] in Pavlov, *Izbrannye trudy*, Natochin et al. eds, pp. 24-6 (25)
[259] Todes, *Pavlov's Physiological Factory*, pp. 61, 301

the Commission for the Improvement of Sanitary Conditions and Decrease of Mortality in the State Medical Council, and the Board of Trustees for all city hospitals in St. Petersburg.[260] Botkin's activities were highly appreciated by his Russian and foreign colleagues as well as by the high military command and the tsar. He was personal physician to the wife of Alexander II.[261]

However, Botkin's major contribution was the introduction of the laboratory to the clinic and his continuous efforts to develop that approach in practical medicine. His commitment to the construction of 'scientific medicine' at the Academy was a part of a general sentiment of the nascent Russian scientific and medical elite that society would benefit from scientific knowledge and practical education of specialists in various fields, medicine in particular. Botkin, like many of his clinical colleagues believed that therapeutics, in contrast to pathology and diagnostics, could not be improved very much through the application of scientific methods in medical practice. But he did believe that experimental research based on the methods of exact sciences would introduce new possibilities to a medicine presently dominated by the traditional anatomo-clinical method. Therefore he promoted laboratory training and physiological knowledge in the education of future physicians. In the inspiring words of Pavlov, "Botkin was the best embodiment of the rightful and fruitful union of medicine and physiology – those two kinds of human activities that raise the building of science of the human organism. ...He sent his students to study at the laboratory, and this high esteem of the experiment by a

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260 Shevchenko, ed, *Professora Voenno-Meditsinskoi Akademii*, p. 117

261 "O sluzhbe ordinarnigo professora Akademii Botkina: Apr. 4, 1862 - Dec. 17, 1890" ["On the Service of Professor Ordinarius Botkin at the Academy"] in *Rossiiskii Gosudarstvennyi Voenno-istoricheskii Arkhiv*, fond 316, op. 60, d. 373, lists 1-200. Botkin's son Evgenii (1865-1918), a physician to Tsar Nicholas II was murdered with the royal family in Ekaterinburg in 1918. See Tatiane Botkine, *A la mémoire de mon père le docteur Eugène Botkine, médicin de la famille impériale Russe*. Paris, 1985 (first published in Russian in Belgrade in 1921). On Doctor Evgenii Botkin ee also N. A. Sokolov (1882-1924), *Ubiistvo tsarskoi sem'i [The Murder of the Royal Family]*, Moscow, 1991, pp. 283-94, first published in Berlin in 1925

clinician is, in my opinion, of no less importance to the fame of Sergei Petrovich [Botkin] than his clinical activity which is known all over Russia."[262]

3. A New Discipline of Physiology: Sechenov's Laboratory

As early as in 1857, during his studies abroad Sechenov determined his physiological credo according to the modern tendencies in the developments of experimental sciences. In his application to the Medical Council of the Moscow and Kazan Universities he pointed to the lack of adequate institutional structures and facilities in Russia needed to acquire experimental skills and methods to teach modern physiology: "Because of the absence of physiological institutes at the Russian universities a physician cannot learn physiology experimentally - in science he is acquainted only with the results, whereas the ways of obtaining these results are for the most part unknown to him. That makes it impossible to develop research skills and an independent critical viewpoint, which are most desirable in a professor." Sechenov further argued that methods of other disciplines, mathematics in particular, were of importance for understanding and explanation the new scenes of physiological inquiry: "The path modern physiology takes, requires the application of advanced mathematics. That has been demonstrated in the remarkable studies performed by Helmholtz, du Bois-Reymond, and Carl Ludwig. My knowledge of higher mathematics, which I acquired at the Engineering School prior to University, gives me the right to believe that I can be at the same level with modern physiology." Sechenov offered his assistance to the Medical

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[262] Pavlov, "Sovremennoe ob"edinenie," in *Trudy obshchestva*, p. 242, cited in Miasnikov, "Vstupitel'naia lektsiia," p. 7

Council of both Moscow and Kazan Universities in ordering and buying apparatus and instruments necessary to set up a new laboratory,[263] but he was never contacted by either of them.

However, his rigorous training in laboratory methods and technique, and the research he had carried out in German laboratories, proved decisive for his appointment to the St. Petersburg Medico-Surgical Academy. Like his colleagues Botkin, Bekkers, and Junge, Sechenov was invited to teach at the Medico-Surgical Academy while he was still studying in Germany (Botkin brought a letter from Glebov to Sechenov in Heidelberg).[264] Later Sechenov recalled:

> Reflecting now on whether I deserved a chair of the experimental science at that time, I say according to my conscience, less than our assistants now, who have not been abroad. They are acquainted with physiological practice in very diverse directions, but I at the time was only able to use frogs, and saw, it is true, many experiments in Ludwig's laboratory, sometimes even assisting in them, but I myself was really acquainted only with those methods, which were linked to my work. They took me because there were not yet any such assistants in Russia and I, with my limited knowledge, was nevertheless the first of the Russians who had partaken of Western science with such leading figures as my teachers in Germany.[265]

Sechenov's call to the Academy reflects the importance placed by its administration on the natural sciences, experimental physiology in particular, in raising the standards of medical training. The Medical Councils of Moscow and Kazan Universities having ignored Sechenov's persuasive rhetoric, demonstrated quite different attitudes, goals and potentialities for the introduction of the laboratory at the university's medical faculties. The supportive recognition by the Academy's Conference

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[263] Koshtoyants et al, eds, *Nauchnoe nasledstvo*, pp. 19-21
[264] Sechenov, *Autobiographical Notes*, p. 88; see also Ludwig to Sechenov, letter d. Vienna, 14 May 1859, cited in Schröer, *Carl Ludwig*, p. 249
[265] Sechenov, *Autobiographic Notes*, p. 99

of Sechenov's abilities to introduce such innovative features as lecture-demonstrations and practical instruction for the students in experimental physiology, was responsible for the immediate funding and assistance in setting up the laboratory and ordering and buying instruments and apparatus necessary for its equipment.

Upon returning from Germany in 1860, Sechenov defended his doctoral thesis at the Academy, and soon thereafter was appointed an adjunct to the physiology chair. The problem of the absorption of alcohol by the blood, which Sechenov had chosen for his dissertation, put him in the center of the research concerned with problems of respiratory physiology. In the dissertation, Sechenov boldly stated: "A physiologist is a physico-chemist who deals with the living organism."[266] N. E. Vvedenskii (1852-1922), Sechenov's disciple at the St. Petersburg University, stated that in his thesis Sechenov referred to a controversy between the two competing schools in physiology - physico-chemical and morphological, and demonstrated the passionate views of a young scientist, a student of du Bois-Reymond and Helmholtz.[267] Just as Ludwig was, in the words of du Bois-Reymond, the *Fahnenträger der Schule,* the standard bearer of a new school of physiology in Germany,[268] Sechenov became an ardent proponent of precise, quantitative, physico-chemical methods in physiology in Russia.

The Academy offered Sechenov a laboratory, which consisted of two large rooms that had formerly served as a chemical laboratory on the lower floor of the

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[266] I. M. Sechenov, *Dannye dlia budushchei fiziologii alkogol'nogo op'ianeniia [Data for the Future Physiology of Alcoholic Intoxication],* St. Petersburg, 1860 in I. M. Sechenov, *Izbrannye proizvedeniia [Selected Works],* Kh. Koshtoyants, ed, in 2 vols, Moscow, 1952-1956, v. 2, pp. 35-98

[267] N. N. Vvedenskii, "Ivan Mikhailovich Sechenov. Nekrolog [Obituary], *Trudy S. Peterburgskogo obshchestva estestvoispytatelei [Proceedings of the St. Petersburg Natural Scientists Society]* (1906) 36 (2): 1-44, in *I. M. Sechenov, I. P. Pavlov, N. E. Vvedenskii. Fiziologiia nervnoi sistemy. Izbrannye proizvedeniia [I. M. Sechenov, I. P. Pavlov, N. E. Vvedenskii. Physiology of the Nervous system. Selected Works],* K. M. Bykiov, ed, Moscow, 1952, pp. 59-81 (64)

[268] Du Bois-Reymond to Ludwig, letter d. Berlin, 9 January 1853, cited in Cranefield, ed, *Two Great Scientists.* p. 78

hospital building, next to the old anatomy theater. There were a few instruments there mainly knives, scissors and forceps, but nothing for the new-style physiology. Sechenov recalled: "Everybody who happened to set up a new laboratory could agree, I believe, that even an experienced researcher spends years on training two or three independent assistants. We, in the 1860's, had even more difficulties in that as everything was new for us and little had been prepared for it." He would later encounter the same difficulties in setting up a new laboratory in Odessa and again in arranging his experimental work at St. Petersburg University's laboratory. And he would have to admit later the generosity of the Academy's budget and President Dubovitskii's support in funding the equipment of his first laboratory.[269]

The Conference encouraged Sechenov to buy necessary apparatus and instruments. It appreciated the fact that he was well acquainted with the workshops and manufacturers in Berlin, and immediately requested the funds: 2,500 roubles from Minister of War.[270]

Instruments purchased by the Medico-Surgical Academy from Sechenov:[271]

	Roubles
For electrophysiology:	
Multiplier with three astatic needles	80
Induction apparatus of du Bois-Reymond	15
Two pairs of platinum electrodes of a special type	24
Twelve elements of Grove[272]	15

[269] Sechenov, *Autobiographical Notes*, p. 101
[270] Koshtoyants et al, eds, *Nauchnoe nasledstvo*, pp. 25-26
[271] *Ibid*, p. 28
[272] 'Gas Voltaic battery', the first real long life battery capable of generating a constant current, was constructed in 1843. It consisted of platinum electrodes in two jars of sulphuric acid with a layer of oxygen above one, hydrogen above the other. Sir William Robert Grove (1811-1896), English lawyer who gave a few decades to experimental natural science.

Two tripods with six various supports	20
Switchboard of Störer	5
Polar switch	5
Interrupter	3
Making and break apparatus	3
Support frame for frog	5
Magnet	1
For blood-gas experiments:	
2 Absorptiometers (Meyer's)	20
Absorptiometer (Bunsen's)	30
Blood-gas apparatus incl glassware, rubber tubes, 12 forceps (Meyer's)	50
Apparatus for extracting electrolytic hydrogen and detonating gas (Bunsen's)	6
Transportation	70

The list of instruments Sechenov acquired, is suggestive of two things: first, that specialized orientation of research Sechenov was going to pursue in his laboratory was nerve and muscle physiology, and absorptiometric studies, in both of which he had obtained excellent bench experience and quite distinguished results. Second is that Sechenov was inspired by the example of du Bois-Reymond's laboratory in Berlin and Ludwig's laboratory in the Josephinum. Despite severe limitation in space and equipment in the late 1850s, these laboratories offered a first hand instruction in laboratory techniques and the newest methods, often worked out before the eyes of the learners. These laboratories also offered first practical skill in designing various physiological devices and apparatuses for the experimenter's own investigations of particular problems. All this was new and exciting and acted as a magnet to attract a number of young physiologists, primarily from Germany and Russia.

Sechenov understood that his new laboratory, which started with small expenditures required more support to meet the needs of experimental physiology, and requested additional funds: "...because of practical studies in chemistry and physiology the expenses of the laboratory have been increased, so for chemical experiments 120 roubles is needed, and for physiological - 200 roubles."[273] The Conference supported his request that another 1000 roubles be allotted for instruments such as a kymograph of Ludwig, a gasometer (100 liters of volume), a myograph of Pflüger, and 28 microscopes. The monthly budget of the laboratory was 30 roubles. Part of this sum was spent on purchasing animals and on payment for taking care of them. Mainly frogs were being bought for 2-5 kopecks a hundred, then rats, rabbits, guinea pigs, fish and lampreys. Officially Sechenov was not supposed to have an assistant; a graduate of the Physicians' Institute who had chosen to specialize in physiology was assigned to the laboratory to assist Sechenov.[274]

The physiology course was the first of the new generation of courses at the Academy that offered lecture demonstrations, laboratory training for the students and research supervision for the selected ones. Sechenov's first course was on electrophysiology, the subject that had so fascinated him during his studies in Berlin. Shaternikov recalled that Sechenov's lectures on animal electricity, accompanied by well executed demonstrations, were very impressive in their novelty and depth and acquainted the students with the most recent techniques of the scientific experiment and taught them to use the language of facts.[275] It can be surmised from the list of instruments that these were only the basic electrophysiological experiments which

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[273] Koshtoyants et al, eds, *Nauchnoe nasledstvo*, p. 28
[274] Popel'skii, *Istoricheskii ocherk kafedry fiziologii*, pp. 54-6
[275] Shaternikov, "Sechenov," in Sechenov, *Selected Works*, p. xvii

demonstrated the phenomena of negative variation in the nerve and muscle using a special arrangement of du Bois-Reymond's devices: the non-polarizable electrodes, the multiplier, the rheochord for changes in the amount of a constant current, the magnetic interrupter of a current, and the key to throw a given current from one pair of electrodes to another. The phenomenon of electrotonus was demonstrated with Pflüger's myograph.

To get an idea of Sechenov's course of physiology we can look at the official program of his lectures for 1860-1861 presented to the Conference of the Academy. Twenty-two lectures out of sixty-four in the course were on respiratory physiology, including lectures on blood as a physico-chemical system, the subject of Sechenov's own investigations at Ludwig's laboratory in Vienna. In his lectures, Sechenov sought to convey to his students the new facts carefully worked out in the laboratory. The students were to gain appreciation of Sechenov's simple presentation of the apparatus and instruments, methods and technique by means of which all these facts had been obtained and tested. In the seventh Lecture, "Means of determining the mass of red blood cells," Sechenov presented the method of Prévost and Dumas[276] of 1821, the latest method of

[276] Jean-Baptiste A. Dumas (1800-1884) a French leading chemist, taught at the École Polytechnique, and at the same time was professor of organic chemistry at the École de Médicine. He then succeeded Louis Joseph Gay-Lussac (1778-1850) at the Sorbonne and lectured for several years at the Collège de France. He is considered the first chemist in France to give practical laboratory instruction to students. Together with Jean L. Prévost (1790-1850; MD in 1818 from Edinburgh), a physiologist from Geneva, published on the size and shape of blood corpuscles: "Examen du sang et de son action dans les divers phénomènes de la vie," *Annales de Chemie et de Physique* (1821) 18: 280-296. In another paper they described the formation of the blood clot and the method of preparing the fibrin for quantitative analysis, "Examen de sang et de son action dans les divers phénomènes de la vie," *Ann. Chim. Phys.* (1823) 23: 50-68. In his discussion of fibrin in the blood Sechenov drew on Johannes Müller's important observations and discussion of the separation of the components of the blood, and his famous filtration experiment, which had shown that fibrin is not inside the red cells. These were reported in the textbook well known to Sechenov, J. Müller, *Handbuch der Physiologie des Menschen für Vorlesungen*, Coblenz, 1840. On Müller's research in that area see P. Mazumdar, "Johannes Müller on the Blood, the Lymph, and the Chyle," *Isis* (1975) 33: 242-253. See also Partington, *History of Chemistry*, v. 4, p. 337

Hoppe-Seyler and Schmidt[277] of 1858 and the results of organic-chemical analysis of fibrin and albumen of the blood introduced by Hoppe-Seyler. Chemical methods and laboratory techniques for study and analyses of bodily fluids, including blood analysis, were presented in Hoppe-Seyler's *Handbuch der physiologisch- und pathologisch-chemischen Analyse,* published in Berlin in 1858, when Hoppe headed the chemical laboratory at Virchow's Institute of Pathology in Berlin. At that time Sechenov worked in the laboratory and got first-hand experience that he could relate to his students.

In the lecture on microscopic analysis of the blood, the central point was a widely known method and device of Karl Vierordt [278] for counting and measuring the volume of red blood cells, and in the lecture on the movement of the blood particular attention was paid to Vierordt's method and device for measuring blood velocity, and to the methods of Alfred W. Volkmann[279] and Carl Ludwig. Apparently, in his lectures Sechenov drew heavily on the German textbooks of the late 1850s and when appropriate to his own bench experience acquired at the German laboratories. Later in his *Notes* Sechenov was somewhat self-critical and ironic about his first course given at the Academy: "It turns out that I was not able to distinguish the important from the secondary in all cases, I could not designate exactly in words the various concepts...

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[277] Alexander Schmidt (1831-1914) carried out basic studies on blood clotting with Hoppe-Seyler in Berlin and also studied gas exchange with Ludwig in Vienna and then in Leipzig, see K. Rothschuh, *A History of Physiology,* transl. G. Risse, New York, 1973, pp. 284-7

[278] Karl von Vierordt (1818-1884), professor of physiology in Tübingen, a student of Johannes Müller. His research interests lay in the area of measurable, quantitative physiological phenomena, especially the gas exchange in respiration and specifically the elimination of carbonic acid. His sphygmograph was the first pulse-recording device. He also investigated blood velocity and the application of spectrophotometry in physiology and chemistry, see *ibid*, p. 242

[279] Alfred W. Volkmann (1800-1877), a student of Ernst H. Weber, professor of anatomy and physiology at Halle, was active in the field of haemodynamics, in which he exchanged the ideas with his teacher Weber and Carl Ludwig. The results of his research in this area were published in his *Die Haemodynamik nach Versuchen,* Leipzig, 1850, see *ibid,* pp. 176, 179

There were some *naïvetés*, but the German textbooks saved me from gross mistakes."[280]

Whereas by the late 1850s experimental physiology was well established in Germany, there was as yet hardly any physiological work done in Russia. Sechenov published his lectures on animal electricity that won him a prestigious *Demidov Prize* of the St. Petersburg Academy of Science in 1862.[281] The importance of the *Lectures* in the formation of the laboratory discipline at the Academy was twofold: it was the first Russian textbook dealing with the concept and methodology of contemporary electrophysiological studies. Secondly, it promoted and consolidated the introduction of experimental methods and instrumentation into practical teaching of medical sciences using a short and dynamic history of electrophysiology. A description of the experiments of Luigi Galvani, Alessandro Volta, Leopoldo Nobili, and Carlo Matteucci. was accompanied by detailed detours into the area of physics with a particular stress on the importance of apparatus in electrophysiology: all successes in the field were determined by developments of instrumentation. Using a multiplier, Matteucci was able to demonstrate the electrical negativity of a cross-section of the muscle and described the electric oscillations in a tetanized muscle. Sechenov valued Matteucci's contribution in contrast to du Bois-Reymond's sharp criticism of Matteucci's experimental results. In his turn, du Bois-Reymond devised a more sensitive multiplier, an improved version of Nobili's galvanometer that made it possible to demonstrate the so-called *Froschstrom*, which had first been detected by Nobili. However, du Bois-Reymond's multiplier was too limited in sensitivity to take readings from individual cells. In spite of the 'downfall' of du Bois's "molecular theory," Sechenov gave credit to the "sparkling wit and talent"

[280] Sechenov, *Autobiographical Notes*, p. 102
[281] I. M. Sechenov, *Lektsii o zhivotnom elektrichestve [Lectures on Animal Electricity]*, St. Petersburg, 1862

of the German scientist, and stressed that du Bois-Reymond's theory posed the problem of molecular structure of nerves and muscles for the first time. Sechenov described in greater detail various modifications of galvanometers including du Bois-Reymond's 'astatic galvanometer' that had been used by a whole generation of researchers to detect and amplify weak bioelectric currents and their direction.[282] Sechenov's appeal to history in his *Lectures* supports the claim that during the same period such discipline builders as Virchow, du Bois- Reymond and Bernard, all used the historical treatment of physiology and allied sciences to promote and legitimate the introduction of experimental methods into medicine.[283]

Sechenov's efforts to create the necessary conditions for independent research and adequate training at his laboratory were appreciated by the Conference: Zinin offered him a recommendation for the position of adjunct in the St. Petersburg Academy of Sciences. Sechenov refused to accept "such a high honor," as he called it, and instead asked for one-year leave to go abroad "in order to get acquainted with the newest developments in the field of physiology."[284] In the fall of 1862 Sechenov was already in Paris to work and study at Claude Bernard's laboratory. Bernard's high esteem among Russian intellectuals of the second half of the nineteenth century, his reputation of "the most skillful vivisectionist in Europe, a very keen observer and a sober philosopher" (in Sechenov's words) attracted Sechenov, and later his successors at the chair of

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[282] Sechenov, *Lektsii*, pp. iii-v
[283] N. Jardine, "The Laboratory Revolution in Medicine as Rhetorical and Aesthetic Accomplishment," *Laboratory Revolution*, pp. 310-21; see also J. Bleker, *Die Naturhistorische Schule, 1825-1845. Ein Beitrag zur Geschichte der klinischen Medizin in Deutschland*, Stuttgart, 1981, Chap. 6; on du Bois-Reymond as a historian of the natural sciences, see H. Boruttau, "Emil du Bois-Reymond als Physiologe und Historiker der Naturwissenschaften," *Berl. Klin. Wschrf.* (1919) 26: 926-8
[284] Koshtoyants et al, eds, *Nauchnoe nasledstvo*, p. 32

physiology at the Academy, Cyon, Tarkhanov, and Pavlov,[285] to study at his laboratory. Bernard regarded Sechenov's experimental work at his laboratory with complete indifference: "...he [Bernard] was not a teacher like the Germans, and he worked out the topics which arose in his mind with his own hands, not leaving his study... this is why it was impossible for someone as myself who came to him for a short time to learn anything in his laboratory."[286]

However, Bernard's wide physiological outlook and his superior abilities in experimenting impressed Sechenov and gave a touch of inspiration to his work performed in the laboratory at the *Collège de France*. Sechenov made the significant discovery of an inhibition mechanism for the reflex processes occurring in the central nervous system.[287] He dedicated his work to Ludwig who in contrast to Bernard, never failed to express a genuine interest in and concern for any of experimental research of his student. Though published in France with an introduction by Bernard,[288] Sechenov's work attracted little notice at the time of its publication. It was in Vienna and Berlin that his work received a warm welcome: he demonstrated his experiments to Ludwig, Brücke, and du Bois-Reymond. Soon Ludwig informed Sechenov that he had succeeded

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[285] On Bernard's influence on Pavlov and the relation of Bernard's scientific vision to that of Pavlov, see Todes, *Pavlov's Physiology Factory*, pp. 45-6; 199-200; 353-54

[286] Sechenov, *Autobiographical Notes*, pp. 106-107 Recollecting that time Sechnov made an interesting remark: "The different aspects of electrical stimulation of the nerves and muscles had not yet at that time came from Germany to the laboratory at Paris, and Bernard still used a *pince electrique*, compasses with copper and zinc ends, for their stimulation." He noted that Bernard was very little acquainted with the German sources, as he did not know German. Sechenov was surprised to hear only two German names, Gabriel Valentine (1810-1883) and Rudolf Virchow at Bernard's lectures. According to Sechenov, it was a physiological chemist Willy Kühne (1837-1900), Sechenov's collaborator at the Pathological Institute, through whom Bernard became acquainted with the Germans.

[287] I. Setchenow, *Physiologische Studien über die Hemmungmechnismen für die Reflextatigkeit des Rückenmarkes im Gehirne des Frosches*, Berlin. 1863. A comprehensive discussion on Sechenov's discovery is found in Koshtoyants, *Essays*, pp. 126-41

[288] I. Setchenov, "Sur les centres modérateurs de mouvements reflexes dans le cerveau de la grenouille," *C. r. Acad. sci.*, Paris (1863) 56: 50-53; 185-187

in reproducing Sechenov's 'beautiful experiments' at one of his recent lectures.[289]

After returning from Paris, Sechenov resumed his work at the Academy. The following year, he published his provocative essay *Reflexes of the Brain*, aimed at making closer connection between mental reactions and the functions of nervous system. As an accomplished craftsman and strenuous worker in the laboratory, Sechenov had exhibited his adherence to the exact methods in physiological inquiry. His methodology for the study of blood gases of 1859, and his experiments demonstrating the inhibition of reflex movements by the nervous centers of 1862 won Sechenov esteem among the leading European physiologists. On the other hand, the *Reflexes of the Brain*, a small treatise of a speculative character, although based on the experimental research on the central nervous inhibition, won him enormous esteem among Russian radical intellectuals, mainly dilettantes in experimental physiology, for whom science was only the 'omnipotent means' for attacking official ideology. The *Reflexes* aroused annoyance in the official circles suspicious of the physiological treatise, which elaborated problems of consciousness and free will, which in view of the orthodox ideology were beyond the laws of nature and history. The censorship department insisted on changing the original title of the treatise, *An Attempt to Establish the Physiological Basis of Psychological Processes*, and on publishing it in a specialized medical journal, not in a widely read monthly review.[290]

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[289] Ludwig to Sechenov, letter d. Vienna, 25 November 1862, cited in Shaternikov, "Sechenov," in Sechenov, *Selected Works*, p. xix; see also Sechenov, *Autobiographical Notes*, p. 108

[290] I. M. Sechenov, "Refleksy golovnogo mozga" ["Reflexes of the Brain"] first published in *Meditsinskii vestnik [Medical Herald]* (1863) 47: 461-84; 48: 493-512. A comprehensive discussion, based on official sources, on Sechenov's troubles with the department of censorship in 1863 and in 1866, when the *Reflexes* appeared in a book form, see Shaternikov, "Sechenov," in Sechenov, *Selected Works*, pp. xx-xxv; Soviet historiography paid much attention to the social response to Sechenov's popular works; as a typical example, see Koshtoyants, *Essays*, pp. 142-52, 157-165. The majority of the historiographical works of the 1980s do not contain any new information or interpretation of the topic. A useful English language

In his letter concerning Sechenov's troubles with the censors, Ludwig expressed anxiety about the official reaction to the publication of the *Reflexes* that was, as he heard, "under a special surveillance." He advised that Sechenov should and would remain a good *Vaterlandsfreund*, a loyal patriotic subject.[291] Apparently Ludwig did not approve Sechenov's involvement in any disputes with officials, as well as in any matters other than laboratory research and teaching. He seems to have felt that political activity was a career-damaging diversion. However, Sechenov's thoughts again were averted from the laboratory: he was deeply affected with the government's decision of 1864 to cancel admission of women to the Medico-Surgical Academy. That prevented Sechenov's future wife, Maria Bokova who had been studying at his laboratory since 1861, from entering the Academy as a student. Sechenov's petition to the Conference of the Academy was of no avail. He was ready to leave the Academy and go with Maria to Vienna to work at Ludwig's laboratory where she could study obstetrics at one of Vienna's clinics. It seems that Pavlov was right suggesting that the *Reflexes* bears evidence of "a strong emotional upheaval": it was "a stroke of genius in Sechenov's thought," with a kind of "personal passion."[292]

Ludwig, in the role of Sechenov's personal and scientific mentor, was very upset by Sechenov's efforts concerning women's education and by his intention to resign, that,

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source on Sechenov's *Reflexes of the Brain* is Todes, *From Radicalism to Scientific Convention*, pp. 249-66

[291] Ludwig to Sechenov, letter d. Vienna, 15 November 1863, cited in Shaternilov, "Sechenov," in Sechenov, *Selected Works*, pp. xx-xi

[292] Koshtoyants published two of Pavlov's letters from September and October of 1929 to Shaternikov, professor of physiology at Moscow University, a close friend and first biographer of Sechenov. In the first letter Pavlov asked for some information concerning Sechenov's relationship with Maria Aleksandrovna Bokova. Pavlov explained his interest in the events of personal life of Sechenov, for the sake of "better understanding and an adequate appraisal of the scientific image of Sechenov." In the second letter he thanked Shaternikov for the information and pointed out that he would "made use of the most general fact that Sechenov was possessed by the emotions of love during writing the *Reflexes of the Brain*. See, Koshtoyants, *Essays*, pp. 151-2

in Ludwig's opinion, would ruin Sechenov's research and teaching career and create him a reputation of a 'troublemaker.' Ludwig believed that the Academy in St. Petersburg was so essential for Sechenov's scientific work and that he should concentrate his energy and talent there.[293] Du Bois-Reymond too was convinced that Sechenov's absorption with such trivia as women's education was obsolete. The German physiologists had no sympathy for this cause.[294] In Sechenov's case, however, the personal was also political.

In the letter cited above, Ludwig also discussed Sechenov's further investigations on central nervous inhibition, which required a great deal of experimental skills and much effort to adjust the current crude methods and techniques to the study of such delicate phenomena as brain mechanisms. Indeed, despite his diversions, Sechenov always favored experimental research, and spent all his time at the laboratory, a habit he maintained throughout his life. He lived in a small apartment in the grounds of the Academy, and, according to A. S. Stal', a former student at the Academy, the light at Sechenov's laboratory, where he usually worked with a group of five to ten students, was seen till late at night.[295] Sechenov was fully absorbed in the experiments related to his new discovery and published 25 articles on the subject primarily in German journals and in greater detail in Chapters 3 and 4 of his *Fiziologiia nervnoi sistemy* that was published in 1866.[296]

Many of Sechenov's former students at the Academy referred to his notable abilities as a lecturer. His lectures often went on for two hours instead of one and a half.

[293] Ludwid to Sechenov, letter d. Vienna, 2 November 1864, cited in Shaternikov, "Sechenov," in Sechenov, *Selected Works*, p. xxvi
[294] Sechenov, *Autobiographical Notes*, p. 109
[295] A. Stal', *Perezhitoe i peredumannoe studentom, vrachem i professorom [What Was Experienced and Thought by a Student, Physician and Professor]*, St. Petersburg, 1908, p. 22
[296] Sechenov, *Autobiographical Notes*, p. 119

The huge lecture-hall was always full, and students often came early to take seats. Sometimes the students expressed their gratitude with an ovation to the professor. However, as Stal' pointed out, despite the reputation of a radical liberal, who affected the minds of the students, that was ascribed to Sechenov by some officials, he communicated with students only in his laboratory and lecture-hall; he was available to every student who was interested in scientific problems, but students never gathered at his place, only his closest associates from the laboratory. Stal' further stressed that Sechenov never sought popularity among students by fine words or liberal views:

> One of the major merits of Sechenov as a lecturer on physiology was his aspiration to confirm all that he said by experiments on animals that were demonstrated before the eyes of his listeners...To formulate ideas from separate facts, to connect various physical, chemical, and anatomical phenomena in one whole, which came to be a biological regularity he did it in such a clear, logical and simple way that it seemed a complete truth to the listeners. For that reason physiology then was the favorite subject for all students of the Academy. [297]

An aesthetic perception of Sechenov as a lecturer is presented by a distinguished physiologist A. F. Samoilov (1867-1930), Sechenov's collaborator at Moscow University's laboratory in the 1890s.[298] An excellent musician, Samoilov referred to Sechenov's voice as a wonderful, clear, slightly sharp, of a high baritone character: "Beautiful diction was combined with masterful speech. He had perfect command of German and French, knew Italian, and his Russian, expressive and accurate, was a model of scientific language. Old-fashioned expressions that he sometimes used added a

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[297] Stal', *Perezhitoe i peredumannoe*, pp. 24-5

[298] On Samoilov see N. A. Grigor'yan, *A. F. Samoilov*, Moscow, 1963; on Samoilov and his collaboration with Pavlov, see Vucinich, *Science in Russian Culture*, v. 2, pp. 315-6, and Todes, *Pavlov's Physiology Factory*, pp. 108, 132

peculiar charm to his speech."[299] Interestingly, that Sechenov in his masterful portrait gallery of the German physiologists in the manner of an admirer of Italian art, also referred to the low quiet voice of Müller and his eyes "burning with indescribable brilliance," to the expression of the eyes of Helmholtz, comparable to the eyes of the Sistine Madonna, and to the "smooth beautifully sounding speech" of du Bois-Reymond.

Sechenov's success and achievements in nerve and muscle physiology were responsible for the specialized orientation of the research pursued at the Academy's laboratory. According to Professor of the Academy L. Popel'skii, Sechenov's course of physiology was demonstrative as far as the means of the laboratory afforded. Experiments in the lectures were related mainly to electrophysiology and physiology of the spinal cord. Sechenov was especially fond of demonstrating the reflex action of the spinal cord, using the Türck-Sechenov method: inhibition of spinal cord activity by irritating the optic nerve of the frog with sodium chloride.[300]

However, the specialized orientation in laboratory training and the lecture-demonstrations could not be explained only by the lack of funds for expansion and diversity. Sechenov simply did not deal with problems related to other areas of physiology: "I worked sometimes alone and sometimes with my students (Matkevich, Pashutin, Voroshilov, Tarkhanov, Litvinov and Spiro) exclusively on the nervous

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[299] "Sechenov i ego mysli o roli myshtsi v nashem poznanii prirody" ["Sechenov and his thoughts on the role of the muscle in our knowledge of nature"] in A. F. Samoilov, *Izbrannye stat'i i rechi [Selected Papers and Speeches]*, Leningrad, 1946, pp. 43-69 (44)

[300] Popel'skii, *Istoricheskii ocherk kafedry fiziologii*. p. 55. Ludwig Türck (1810-68) from Vienna, studied the effect of a partial section through the spinal column in 1857. He also discovered the laws concerning the secondary degeneration in the nervous system in 1849. In 1861, together with Johannes N. Czermak (1828-73), he received the Montyon Prize of the Paris Academy of Sciences for the invention of the laryngoscope. See E. Lesky, "Ludwig Türck. Neuroanatom und Neurophysiologe," K. E. Rothschuh, *Von Boerhaave bis Berger*, Stuttgart, 1964, pp. 129-33

system of the frog."[301] A few examples of absorptiometric research done by Sechenov during that period were related to the improvement of his blood gas pump. His idea of using a thin metal tube instead of a rubber one where the receiver for the absorbing liquid was connected with the manometer seemed to be useful for devising a better version of his apparatus for the extraction blood gases.[302] Sechenov mentioned in his *Notes* that this idea came to him at Regnault's lectures on thermometry that he had taken during his studies with Bernard in 1862. The course "was instructive in the highest degree" for Sechenov, as Regnault demonstrated at his lectures a modification of his air thermometer in which the manometer was connected with the air cylinder by a very thin metal tube.[303] However, it was only a brief period when Sechenov returned to the research in blood gases: his thoughts were "diverted for many years by the experiments done in Bernard's laboratory."[304]

Sechenov's research interests did not shift during the decade, so the orientation and field of research of the inner circle of his assistants and students was concentrated primarily on nerve and muscle physiology. His laboratory, designed for 'physical physiology,' proved to be extremely individualistic. The annual account of the work of the laboratory submitted by Sechenov to the Conference of the Academy for 1870 reveals the scope of research carried out by him and under his guidance:

> I. Sechenov: is preparing for publication the research on the effects of intensified induction impulses on nerves, and at present investigates the problem on the absorption

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[301] Sechenov, *Autobiographical Notes*, p. 119
[302] I. Setchenow, "Pneumatologische Notizen," *Z. ration. Med.* (1861) 3 (10): 285-292; and "Neuer Apparat zur Gewinnung der Gase aus dem Blut," *Z. ration. Med.* (1865) 3 (23): 16-20
[303] Henry Victor Regnault (1818-1878), professor of physics at the Collège de France and from 1845 to 1871 director of the Royal Porcelain Factory in Sèvres. At the time when Sechenov studied with him Regnault was known for his interest in the physical state of gases and his studies of respiration (accurate gas analysis) published together with Jules Reiset (1818-1896) in 1849. See Partington, *History of Chemistry*, v. 4, pp. 396, 428
[304] Sechenov, *Autobiographical Notes*, p. 107

of carbon dioxide in the blood; V. Pashutin: has completed his research on digestion in the intestine; K. Voroshilov: is working on the nitrogen exchange in the body, investigates the problem of nutritive equivalents of meat and leguminous plants; P. Spiro: prepared for publication physiological topographical research on the spinal cord and investigates the innervation of the respiratory center in the frog; I. Tarkhanov: published 1. results of his research on summation of electrical impulses by the nervous centers; 2. heat effect on the sensible nerves, the spinal cord and the brain in a frog; A. Tyshetskii: is doing research on the character of movements caused by the direct electrical stimulation of the spinal cord; M. Litvinov: examines the absorption of carbon dioxide by colloids.[305]

Although during the decade of Sechenov's work at the Academy, the laboratory had become essential for both scientific and educational purposes, laboratory training still played an insignificant role in medical education in Russia, even at the Academy. Only advanced students aiming at an academic career were welcomed in Sechenov's laboratory where they acquired adequate skills by assisting and following Sechenov's own experimental work. The key idea for Sechenov in his teaching career at the Academy was 'laboratory training by experimental studies.' Even more important was 'the method' that comprised the ability to determine a solvable problem, to adapt or if necessary to devise the instrumentation to study it, to carry out the experiment with all possible precision and finally to interpret the results. Although the orientation Sechenov gave to his students was rather narrow, the main result was that his most successful students entered the Russian academic market with definite research objectives and excellent experimental skills. In most cases the objectives were patterned according to their teacher's approach to physiology: I. R. Tarkhanov, V. K. Voroshilov, and P. A. Spiro were rightly credited with the important experimental work in neurophysiology, in

[305] Koshtoyants et al, eds, *Nauchnoe nasledstvo*, pp. 50-1

contrast to the research aims of V. V. Pashutin (1845-1901) whose early interest in neurophysiology shifted to problems of physiological chemistry and pathology.[306]

Sechenov's work on the physiology of the nervous system depended primarily upon results from electrophysiology, and upon a limited variety of techniques. We can assume that the technique of vivisection and its associated instrumentation was totally absent from Sechenov's experimental practice. His unwillingness to use warm-blooded animals was known among his students and colleagues. Commented Tarkhanov:

> I remember how entering the laboratory and on hearing yelps and screams of animals at vivisection which was being done by his students, Sechenov used to reproach them for not anaesthetizing the animals enough; sometimes he held his ears or just ran out of the laboratory not to hear sufferings of the animals. He in no way could take upon himself the viewpoint of his famous teacher Claude Bernard, who once had said that during the experiment he saw neither blood nor sufferings of the animals as he gave himself to the leading idea of the experiment.[307]

Frederic L. Holmes draws attention to the interesting fact that, in the nineteenth century experimentations in which an isolated muscle connected to a segment of nerve was used to study muscle contraction and nerve conduction, frogs, in Helmholtz's words 'the old martyrs of science,' were especially prominent.[308] Du Bois-Reymond performed all his delicate measurements of the currents and potentials within nerves and muscles on frogs and parts of frogs; the current that flows between connected skin (high

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[306] I. R. Tarkhanov and V. V. Pashutin, both became professors of the St. Petersburg Medico-Surgical Academy (in the 1890s Pashutin was appointed the Head of the Academy), V. K. Voroshilov - professor at Kazan University, and P. A. Spiro – professor at Novorossiisk University, see N. A. Grigor'yan, "O pervoi russkoi fiziologicheskoi shkole" ["On the First Russian Physiological School"], *Istoriia biologii* (1975) 5: 137-51; see also A. A. Mozzhukhin, "Fiziologicheskie shkoly v Voenno-Meditsinskoi Akademii" [The Physiological Schools at the Medico-Surgical Academy"] in *Shkoly v nauke [Schools in Science]*, Moscow, 1977, pp. 443-7

[307] I. R. Tarkhanov, "Pamiati professora I. M. Sechenova" ["On the Memory of Professor I. M. Sechenov"], *Trudy obshchestva russkikh vrachei [Proceedings of the Society of Russian Physicians]*, St. Petersburg] (1906) 73: 69-75 (73)

[308] F. L. Holmes, "The Old Martyr of Science: The Frog in the Experimental Physiology," *Journal of the History of Biology* (1993) 26: 311-328 (326)

potential) and muscle (lower potential) was simply known as *Froschstrom*. Sechenov mastered the refined experimental techniques in the laboratories of du Bois-Reymond and Helmholtz. That proved crucial in a series of elegant experiments related to the investigation of the conditions under which inhibitory phenomena in both the motor reflexes and the rhythmic work of the lymph heart occurred. These experiments were performed in Graz University's laboratory of Alexander Rollet, in 1867.[309] Investigating the interrelationship between the central and peripheral portions of the nervous system, Sechenov was able to trace the presence of periodic rhythmic phenomena in the central nervous system in the frog. Stimulating the surface of the skin and the central end of sciatic nerve he determined the phenomena of the "summation of separate stimuli into coordinated movement by the nervous centers."[310]

Even though Sechenov studied with Bernard and Ludwig whose experimental physiology was centered upon vivisection of warm-blooded animals, Sechenov apparently did not master the necessary operative technique to use animals other than frogs. He mentioned in his *Notes* that he had learned several vivisectional experiments at Ludwig's laboratory in Vienna but he never incorporated vivisectional demonstrations into his lectures. Later he argued that vivisectional demonstrations on warm-blooded animals were intolerable at the lectures, and referred to the authority of Helmholtz and Brücke who did not use them for lecture demonstrations. Sechenov stressed that the only place for such bloody experiments was the laboratory, so he used only demonstrations

[309] I. Setchenow, *Über die electrische und chemische Reizung der sensiblen Rückenmarksnerven des Frosches*, Graz, 1868. Sechenov's experiments in Rollet's laboratory are well documented in his letters to Maria Bokova from Graz, published in Koshtoyants, *Essays*, pp. 130-4

[310] Sechenov, *Über die electrische und chemische Reizung*, published in Sechenov, *Selected Works*, pp. 177-211 (191-2)

with frogs in the course on nerve and muscle physiology.[311]

Similarly to vivisectional technique, chemico-physiological methods were not employed in Sechenov's research. Besides, the supply of the laboratory with equipment necessary for studies in other areas of physiology was rather limited. However, Sechenov encouraged his students to master varied physiological techniques and methods, but was reluctant to supervise any research involving vivisection or any study in physiological chemistry. Many years later he acknowledged that whenever he had been dealing with chemical problems it was problems that required physical not chemical methods for their solution.[312] In this connection Pashutin wrote:

> Unfortunately, experimental researches in Sechenov's laboratory were focused exclusively on physiology of the nervous system, the experiments were performed with rare exception on frogs. Training in physiological chemistry was poor. Sechenov's supervision in the study on chemical problems could not give us necessary help. To use the advice and the laboratory of other professors seemed unethical.[313]

Sechenov was aware of the increasing need for detailed knowledge in methods employed in physiological chemistry for his students, and his translation of one of the first textbooks in the field, Willy Kühne's *Lehrbuch der physiologischen Chemie* is telling in this respect.[314] The *Lehrbuch* was a course of lectures Kühne had given at the Berlin Pathological Institute when he succeeded Hoppe-Seyler at the laboratory of medical chemistry. Sechenov had worked with Kühne at du Bois-Reymond's laboratory and was acquainted with his chemico-physiological methods and their application to the

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[311] I. M. Sechenov, "Zapiska o prepodavanii fiziologii cheloveka i vysshykh zhivotnykh na Vysshykh zhenskikh kursakh," 1894, see Koshtoyants et al. eds, *Nauchnoe nasledstvo*, p. 180

[312] Sechenov to A. M. Liapunov, letter d. Moscow, November 1892, in Koshtoyants et al, eds, *Nauchnoe nasledstvo*, p. 225. A. M. Liapunov (1857-1918), Sechenov's brother-in-law, was an outstanding mathematician of the St. Petersburg mathematical school of P. L. Chebyshev.

[313] V. V. Pashutin, *Avtobiografiia [Autobiography]*, St. Petersburg, 1899, p. 4

[314] W. Kühne, *Lerhbuch der physiologischen Chemie*, Leipzig, 1866-1868; V. Kune, *Uchebnik fiziologicheskoi khimii*, transl. I. M. Sechenov, St. Petersburg, Part 1, 1866; Part 2&3, 1867; Part 4, 1868; on Kühne research group see Fruton, *Contrasts in Scientific Style*, pp. 80-2

study of muscular contraction and innervation. That issue became of particular interest to Sechenov during his work on the *Fiziologiia nervnoi sistemy*, his major monograph of the period.

Now let us look more closely at Sechenov's research objectives related in the *Fiziologiia.* Sechenov based his monograph on the critical review of the voluminous work in the field and incorporated the results of his own experimental work, aimed at further development of his theory of central nervous inhibition, an important issue that came into focus after Sechenov's discovery of specific inhibitory centers in 1862. Sechenov attempted to explain the phenomena of nervous excitation and the ability of the nerve to conduct excitation in strictly physico-chemical terms. Even more important, according to Vvedenskii, was that "for a long time in Russia this book was the only source in the field. For clearness of statement, strict critical method, and the manner of posing problems this book can be considered a model."[315]

According to Sechenov, electrophysiology was to define every possible physical and chemical property of nerve and muscle at rest and changes of these properties when nerve and muscle are active.[316] Therefore investigation of electrical phenomena in muscles and nerves was of crucial importance for understanding the nature of nerve excitation and muscle contraction. Sechenov gave a detailed description of Hermann Helmholtz's set of experiments devised for measuring the velocity of the nerve impulse and for demonstrating the generation of heat and the chemical change in an isolated muscle during contraction.

[315] Vvedenskii, "I. M. Sechenov. Nekrolog," in *Sechenov, Pavlov, Vvedenskii*, Koshtoyants, ed, p. 72
[316] I. M. Sechenov, *Fiziologiia nervnoi sistemy [Physiology of the Nervous System]*, St. Petersburg, 1866, p. 62

Another important issue under discussion was nerve excitation. Du Bois attempted to reduce nerve excitation and muscle contraction to electromotive forces and that aspect of his theory drew most criticism. At that time a "theory of identity" was wide spread, according to which nerve excitation was likened to an electrical wave. This theory was challenged by Helmholtz's investigation of 1850, done with the myograph of his modification, which established that the speed of transmission in nerves is considerably less than that of electrical transmission in a normal conductor. Although Helmholtz favored an electrical theory of the transmission of nerve impulses, he thought that the underlying mechanism for nerve and muscle action would probably be chemical in character.

Du Bois-Reymond's student, Ludimar Hermann (1838-1914), in place of the physical reductionist account of his teacher's electromolecular theory proposed his 'alteration theory,' a 'physiological model' of nerve and muscle action in which he incorporated all that was known about the chemical composition of nerves and muscles in the resting state, in activity, and in *rigor mortis*. Hermann's theory was adopted widely by physiologists such as Eduard Pflüger (1829-1910) and Julius Bernstein (1839-1917), who worked with Hemholtz in Heidelberg and with du Bois-Reymond in Berlin.[317] Though he was otherwise loyal to du Bois-Reymond, Sechenov adopted Hermann's alternative theory; he also translated and published in St. Petersburg Hermann's *Handbuch der Physiologie* of 1864 and later the forth edition of his *Grundriss der Physiologie des Menschen* of 1873. Sechenov's interest in Hermann's

[317] On the chemical approach and on Bernstein's electrochemical theory see an excellent article by T. Lenoir "Models and Instruments in the Development of Electrophysiology, 1845-1912" in *Historical Studies in the Physical and Biological Sciences* (1986) 17(1): 1-54 (20)

works might be explained by Hermann's chemical approach to muscular physiology and his tendency to deal with the physiological problems in a mathematical manner.[318]

From the mid-1860s there were two main approaches in studies of the nature of nerve excitation: the physical theory of classical physiology and the theory of chemical transmission of nerve excitation and conduction. Sechenov believed that spontaneous chemical processes were the basis of nervous activity.[319] In the *Physiology of the Nervous System* Sechenov explicitly stated that chemical changes were the basis of nerve excitation: "The transition of the nerve from rest to excitation could serve as an indication of chemical transition inside the nerve when it is active."[320]

By the late 1870s du Bois-Reymond in his search for a clear concept for the molecular mechanism of contraction, suggested that a "secretion" of stimulating substances occurred at the borders of the contracting elements ("contractile substances"): "Of the known natural processes which could mediate excitation, as far as I can see, only two come under consideration. Either stimulating secretion should happen at the border of the contractile substances in the form of a thin layer of ammonium or lactic acid or some other substances exciting muscles intensely. Or the effect must be of an electrical nature."[321] However he still remained convinced in the electrical nature of nerve excitation.

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[318] Hermann's *Grundriss* were published in fourteen editions from 1863 to 1910. Sechenov translated the second edition of 1864. It was the first among Sechenov's numerous translations of contemporary physiological literature. In turn, Hermann was interested in Sechenov's absorptiometric investigation. The *Grudriss*'s chapter on blood gases contains a detailed account on Sechenov's method and results. See L. Hermann, *Grundriss der Physiologie des Menschen*, Berlin, 1867, pp. 46-49; *Grundriss*, 5th ed, 1874, pp. 42-47

[319] Sechenov, *Lektsii*, p. 194

[320] Sechenov, *Fiziologiia nervnoi sistemy*, pp. 21, 36

[321] E. du Bois-Reymond, *Gesammelte Abhandlungen z. Muskel-und Nervenphysik*, Leipzig, 1877, p. 36

Investigating the problem of nerve excitation, Sechenov determined the conditions under which excitation was possible: the influx of arterial blood to the nerve, the connection of the nerve with the nerve centers, and the change of rest and excitation in the nerve. He and his students performed numerous experiments with an impaired blood supply to the nerve and presented a convincing proof that a change in the normal process of metabolism in the nerve first of all resulted in disturbances in the excitability of the nerve and in the corresponding physiological indices of that excitability: "If the blood supply [to the nerve] is stopped, for a short of time, 5-10 minutes, resumption of blood supply causes the nerves to regain their excitability; otherwise the excitability disappears and the nerve dies. This fact clearly indicates the close link between the chemical activity of the nervous tissue and the physiological property under study [excitability]."[322] The experiments also showed that similar disturbances in the excitability of the nerve occurred upon severance of the nerves from the nerve centers. Having these experimental data, Sechenov advanced the idea that the ganglia represent "a kind of nutritive centers, the activity of which maintains the anatomical, chemical and physiological integrity of the nerve fiber [sensory fiber]."[323]

According to Sechenov's chemical conception, in the tissue of the animal organism there occurred a synthesis of special substances, "unstable chemical combinations," the presence of which was indispensable both for muscular contraction and for conduction of nervous excitation. Sechenov believed that these processes in the nervous and muscular tissues depended on a constant influx of nutritive substances and

[322] Sechenov, *Fiziologiia*, p. 21
[323] *ibid*, p. 77

oxygen.[324] Sechenov built his ideas on the results of Ludimar Hermann's researches on chemical processes in muscles reported in the revised third and forth editions of Hermann's textbook *Grundriss der Physiologie des Menschen.* Hermann envisioned a cyclical-chemical pathway in which, during the restitutive or synthetic phase, glycogen and oxygen were combined with some - as yet unknown - protein into what he termed an "energy generating" [krafterzeugende] or "inorganic" substance. He supposed that this substance was highly unstable.[325]

All that was known at the time regarding chemical properties of nerve fiber was that nervous fiber tissue at rest had a neutral reaction and during activity, acid. The only claim that Sechenov could derive from this fact was that the activity of the nerve was connected with "chemical transformation" within the nerve and that the basis of the nervous activity was the process of oxidation: "Of course it is impossible to draw any important conclusions from such a meager store of data. But the change in nerve reaction in the transition from rest to activity may serve as a clue that the latter state is related to chemical upheavals within the nerve. New facts will be revealed in the future to confirm that the character of these processes is bound to oxidation."[326]

The chemical side of the process of excitation was not confirmed experimentally till the 1920's. However, the inadequacy of the physical approach to the process of excitation was evident to some German physiologists by the end of the nineteenth century. Max Verworn (1863-1923), Pflüger's successor at the University of Bonn, was anti-reductionist, he took his chemical stand on colloid chemistry as the peculiar essence of life, a kind of vitalism. Being himself especially interested in the physiology of the

[324] *ibid*, p. 79
[325] Hermann, *Gründriss*, 1874, pp. 229-30. See also Lenoir, "Models and Instruments," p. 21
[326] Sechenov, *Fiziologiia*, p. 23

nervous system, he objected to the reductionism implied in the 'wire' analogy: "In this case one should consider as a false principle the assumption that the process of propagation of excitation in nerve is a strictly physical phenomenon. In this respect the comparison of a nerve with a wire which conducts an electrical current was not appropriate."[327] However, the 'electromotive theory' of du Bois-Reymond and Hermann's 'alteration theory,' both physical in their essence, were both crucial steps in exploring the properties of nerves and muscles at the molecular level. Sechenov's participation in the electrophysiological researches of the time, and his efforts to convey the technical content of German electrophysiology and to make theoretical and practical developments in the field ready available in Russia became one of his most substantial contributions to Russian nineteenth-century laboratory science.

In 1866 Sechenov published a revised version of his *Reflexes of the Brain.* The book was forbidden for sale by the St. Petersburg Censorship Committee on the grounds, that "it undermines the moral foundation of society." However, the fate of the book was decided favourably in official correspondence between Head of the Ministry for Justice Prince S. N. Urusov, Attorney-General P. A. Tisenhausen and the Office of the Ministry for the Interior: "Professor Sechenov's teaching, if it erroneous, must be decided upon by means of scientific discussion, and not through a legal process."[328] Obviously, the whole matter caused Sechenov much trouble. Although he had deserved a reputation of a thorough materialist in the opinion of Minister for the Interior, Count P. A. Valuev, the influential and "benevolent" (in Sechenov's words) Dubovitskii seemed

[327] M. Verworn, *Allgemeine Physiologie. Ein Grundriss der Lehre vom Leben*, Jena, 1895, p. 59. Verworn's monographs *Vitalismus und Neovitalismus*, *Allgemeine physiologie*, reflected his tendency to discern the general and theoretical issues behind the phenomena, see Rothschuh, *History of Physiology*, pp. 302-3
[328] Cited in Shaternikov, "Sechenov," p. xxiv

to ignore the biased opinion of some high officials. The Conference headed by Dubovitskii had always supported Sechenov, and valued him as a devoted scientist and a mild, decent man.

Sechenov's distress over this second political episode showed itself in a bout of physical and mental exhaustion. His teaching duties - lectures and practical training for the students, the translation and editing of three voluminous German textbooks, and the intensive research required a great deal of work. The laboratory in the old building in which Sechenov spent all the time was situated over a unused cellar full of with water (as became known later), and that also added to Sechenov's state of fatigue and anxiety. On Botkin's advice, Sechenov took a year's leave for medical treatment in Carlsbad, and half a year spent in Graz, working at Alexander Rollet's laboratory.[329]

Sechenov returned to St. Petersburg in 1868. He left the Academy and his first laboratory two years later, in 1870. A brief account of that period will be useful for understanding the reasons for Sechenov's resignation. Recollecting that time, he pointed to "the change of the tone in the upper echelons of the Academy." By 1868, the "triumvirate," Dubovitskii, Zinin, and Glebov, had left the Academy. Sechenov's remark obviously referred to the new Head of the Academy N. I. Kozlov (1814-89), appointed soon after Sechenov's return from abroad, in 1869.[330] Kozlov was a man of learning; he had studied medicine in Kazan, Dorpat, Vienna, Paris, and Zurich, and worked as professor of anatomy at Kiev University for twelve years. He had deserved a reputation as an experienced administrator while working at the War Ministry's Medical

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[329] Sechenov, *Autobiographical Notes*, p. 122

[330] Presidency was abolished after Dubovitskii left the Academy in 1867: he accepted the position of the Chief Medical Inspector at War Ministry. Soon thereafter he died. Zinin moved to the St. Petersburg Academy of Sciences.

Department. However, according to the historian Ivanovskii, Kozlov became an "evil genius" for the Academy: "...as if a complex mechanism, adjusted and renovated by Dubovitskii, went astray. Under these circumstances and because the Conference was enlarged (new members were all graduates of the Academy's Institute of Physicians), the meetings of the Conference became an arena of arguments that were far beyond the scope of scientific and administrative matters."[331]

Not surprising that Sechenov's open criticism of the Institute of Physicians and the policy of considering only the Institute's graduates for positions at the Academy created opposition among the members of the Conference: "I did not make a secret of my opinion about the Institute of Physicians. Therefore I was not a favourite in the professors' midst, with the exception, of course, of S. P. Botkin and V. L. Gruber." Sechenov argued against privileging the graduates of the Institute over the graduates of the Universities; he believed that such practice was obsolete and even harmful for the Academy, and referred to the German universities' tradition according to which scientific merit was the only criterion for the successful candidate.[332] In November 1869 two of Sechenov's protégés to the Academy's chairs, the histologist A. E. Golubev and the zoologist Ilia Mechnikov, were voted down despite the scholarly reputation of both candidates. By that time, Mechnikov was already known for his embryological studies and publications, and Golubev had proved his research abilities at the laboratories of Alexander Rollet and Ernst Brücke. The Conference preferred F. N. Zavarykin and E. Brandt: both were the graduates of the Institute of Physicians but of quite ordinary, if not

[331] Ivanovskii, ed. *Istoriia Imperatorskoi Mediko-khirurgicheskoi Akademii*, p. 602
[332] Sechenov, *Autobiographical Notes*, p. 125-6

dubious, scientific abilities.[333] Sechenov was frustrated by the open disregard of his opinion and sent in his resignation. In a letter to Mechnikov, describing that ill-fated meeting, Sechenov three times mentions Kozlov and his improper role in those matters.[334]

A close look at the financial documentation of the Academy shows that despite the substantial support of natural sciences at the Academy, the expenditures for the physiological laboratory appear to have declined after Dubovitskii left the Academy in 1867. In total, Dubovitskii's funding on instruments and equipment was 3500 roubles. During the last three years of Sechenov's stay at the Academy there is no record of purchasing any new equipment and instruments for the laboratory. [335] Furthermore, during that time Sechenov never expressed any interest to the new Anatomo-Physiological Institute with expanded research facilities and spacious laboratory that was nearly finished by 1870. He also never mentioned his personal arguments with Kozlov, but the total lack of understanding and cooperation between the two men is obvious in contrast to Dubovitskii's supportive attitude towards Sechenov that proved pivotal in Sechenov's activities at the Academy.

Leaving the Academy, Sechenov recommended Ilia Cyon as the most deserving candidate for the chair of physiology.[336] Similarly to Mechnikov and Golubev, Cyon was from outside of the Academy, and had an excellent reputation as a researcher and

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[333] See Sechenov's *Note*, presented to the Conference in 1869, regarding scientific merits of Zavarykin and Golubev as candidates to the Academy's chair of histology, and of Mechnikov and Brandt, in Koshtoyants et al, eds, *Nauchnoe nasledstvo*, pp. 186-93

[334] Sechenov to Mechnikov, letter d. St. Petersburg, 16 November 1869, in S. Ia. Shtraikh, ed. *Bor'ba za nauku v tsarskoi Rossii. Neizdannye pis'ma I. M. Sechenova, I. I. Mechnikova i dr.[Struggle for Science in Tsarist Russia. Unpublished Letters of I. M. Sechenov, I. I. Mechnikov]*, Moscow-Leningrad, 1931, pp. 57-8

[335] *Ross. Gos. Voen.-ist. Arkhiv*, fond 1 for 1860-70

[336] Sechenov to Mechnikov, letter d. St. Petersburg, 19 Apr. 1870, in *Bor'ba za nauku*, p. 59

teacher, who contributed much to the organization of the laboratory at St. Petersburg University. It is difficult to guess whether Sechenov could possibly foresee the turmoil caused by Cyon's appointment to the Academy. What might be surmised is that Sechenov was sure that his laboratory would benefit from the research, teaching, and managerial talents of Cyon.

4. A Few Steps Further: Cyon's Physiological Laboratory at the Medico-Surgical Academy

Among nineteenth century Russian physiologists Ilia Faddeevich Cyon (1842-1912) is a controversial and somewhat obscure figure: his name was said either with admiration or with scarcely concealed enmity. Everything about him was extraordinary: his experimental talent and scientific productivity, his quarrelsome disposition and the sharp turns of his ideological viewpoints. Opinions about him varied considerably. A physiologist A. A. Ukhtomskii (1875-1924) called Cyon a "brilliant teacher and researcher,"[337] I. I. Mechnikov, on the contrary, noted: "Many who knew him, including me, did not like him greatly for his wicked character and inability to take a somewhat moral viewpoint."[338]

The striking contrast between Sechenov and Cyon, usually drawn by the Soviet historians of science, is often based on the personal qualities and the sociopolitical impact which these two physiologists made on Russian society. In his biography of Sechenov the Soviet historian of psychology, Iaroshevskii, mentions only that Cyon was

[337] A. A. Ukhtomskii, "I. M. Sechenov v Peterburskom-Leningradskom universitete" ["I. M. Sechenov in St. petersbur-Leningrad University], *Fiziologicheskii Zhurnal SSSR* (1954) 40(5): 527-539 (529)
[338] Mechnikov, *Stranitsy vospominanii*, p. 10

"an immoral man and evoked everybody's hatred" for his reactionary views. Another biographer of Sechenov, Koshtoyants, though mentioning Cyon's outstanding scientific accomplishments, focused mainly on the progressive values of Sechenov's activities and Cyon's task "to eradicate the materialistic outlook from the minds of youth."[339]

Apart from their political views which were considered by their contemporaries as diametrically opposed one to the other, and apart from the dissimilarity of their characters, careers, and reputations, Sechenov and Cyon had much in common. Both were accomplished experimenters and the first Russian physiologists whose scientific merits were highly appreciated by their famous teachers and later colleagues in Germany and France. Both were strong and respected advocates of the laboratory in the leading Russian institutions, the St. Petersburg Medico-Surgical Academy and University, and both made major contributions to the rise of experimental physiology in Russia. Both trained a number of researchers in their laboratories who later made their teaching and research careers at various Russian universities, and both greatly influenced further development of physiological thought and expertise in Russia.

Cyon began his studies at the Warsaw Medico-Surgical Academy and then at the medical faculty of Kiev University. In 1858 he entered Berlin University where he studied with du Bois-Reymond, Virchow and the neuropathologist Robert Remak (1815-1865) who maintained a close identification with Jewish-Polish culture. Remak's academic career was not successful despite the support of Alexander Humboldt, Schönlein, and Müller, in whose laboratory Remak had worked for some time. However. Remak's scientific reputation was very high: he made important contributions to

[339] Iaroshevskii, *I. M. Sechenov*, p. 195; Koshtoyants, *Essays*, pp. 158-160; 291

comparative and microscopical anatomy, histophysiology, embryology and cytology that demonstrated his wide scientific outlook and diverse research interests.[340]

Remak suggested to Cyon a research topic for a doctoral dissertation related to impairments of the nerve muscle apparatus in chorea, and the connection of chorea and rheumatic condition of the joints and the heart. Although Cyon's dissertation was essentially clinical, it contained some of the most important lines of his future experimental inquires. The dissertation was well accepted and published in a medical annual.[341] Studies with Remak determined Cyon's research priorities and shaped his scientific outlook. One can trace Remak's influence in some of Cyon's physiological works of that period. Remak's investigation of nerve tissue and his discovery of ganglion cells in the human heart, as well as his research on the function of the sympathetic nervous system might have played a certain role in turning Cyon's attention to the innervation of the heart, which became his long-lasting interest. Another of Remak's works, on galvanotherapy (1858),[342] contained extensive physiological investigations alongside therapeutic and technico-methodological research. That work might well have inspired Cyon's later research on electrotherapy that won him the Gold Medal of the French Academy of Sciences in 1870.[343]

In 1865 Cyon returned from abroad. To be considered for an appointment Russia, he defended his dissertation on chorea at the St. Petersburg Medico-Surgical Academy, and soon thereafter obtained the position of assistant at the Academy's

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[340] E. Hintzsche, "Robert Remak," in *Dictionary of Scientific Biography*, v. 11, pp. 367-70
[341] E. Cyon, *De Choreae indole Sede et Nexu cum rheumatismo Articulari, Peri et Endocarditide*. Dissert. Inaug., Berlin, 1864; Cyon, "Die Chorea und ihr Zusammenhang mit Gelenk-Rheumatismus, Peri- und Endocarditis," in *Wien. Med. Jahrbücher* (1865) 2: 115-131
[342] R. Remak, *Galvanotherapie der Nerven- und Muskelkrankheiten*, Berlin, 1858. The work was dedicated to A. Humboldt.
[343] Élie de Cyon, *Principes d'Electrothérapie*, Paris, 1873; I. F. Cyon, *Osnovy elektroterapii (per. s frants.) [Fundamentals of Electrotherapy (transl. from French)]*, St. Petersburg, 1874

department of nervous diseases and mental disorders, headed by a well-known psychiatrist, Ivan Mikhailivich Balinskii (1827-1902). As a new appointee, Cyon was sent to Germany to study mental and nervous diseases for three years. He published four articles on the subject in German and Austrian journals: two on the problem of dorsal tabes and two on the care of mental patients and the asylum (his critical and experimental interpretation of the theories of dorsal tabes in 124 pages he published separately).[344] That alone would have been unusually fruitful result. But beyond fulfilling his research plan for the chair of mental diseases, Cyon published about thirty articles in German, French, and Russian, in which he presented the results of his physiological investigations, and polemics on the problems related to the experimental part of his work.[345]

The scope and diversity of Cyon's research interests were quite astonishing. No one among his most harsh critics at the Medico-Surgical Academy could ever dream of such productivity during their studies in Europe. One can allude to Sechenov's reference letter, presented to the Conference of the Academy, on the research work done by the graduate of the Institute of Physicians, N. F. Zavarykin, in 1866: "Dr. Zavarykin spent the first year of his research trip at Ludwig's laboratory with benefit, studying histological methods. The remaining three years Zavarykin solely was engaged in practical exercises in chemistry and other matters for which there is no need to stay abroad as all necessary means for such studies are available at home." The work "Zur Anatomie der Niere," published under both names (the usual practice at Ludwig's

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[344] E. Cyon, *Die Lehre von der Tabes dorsalis, kritisch und experimentell erläutert*, Berlin, 1867; E. Cyon, "Über Irrenpflege und Irrenanstalten," *Virchows Arch.* (1867) 42: 149-190

[345] A full list of publications is presented in Cyon's, *Die Gefässdrüsen als regulatorische Schutzorgane des Zentral-Nervensystem*, Berlin, 1910, pp. 359-371; see also Artemov, *Ilia Faddeevich Tsion*, pp. 60-73

laboratory), was presented by Zavarykin as his original research. Sechenov's verdict was expressed in his usual elegant but straightforward manner: "Mr. Zavarykin in this work was an extraordinarily skillful performer of Professor Ludwig's instructions."[346] It was on that ground that Sechenov was against Zavarykin's appointment to the chair of histology in 1869.

Cyon deserved the reputation of a skillful experimenter in three of the most celebrated laboratories of Europe. In the laboratory of du Bois-Reymond, Cyon, together with his brother Moisei, started investigations on the problem of the innervation of the heart. He continued his researches at Ludwig's laboratory in the Leipzig Physiological Institute, and published his results on the problem of the heart functions: the influence of temperature on the heartbeat (first discovered by E. H. Weber in 1846) and the rate of contractions in an isolated segment of the heart.[347] The next year he completed his account of the innervation of the heart, showing that sympathetic cardiac nerves had an effect opposite to that of the vagi: they increase the heart rate.[348] He also studied the nerves of the vessels and of the peritoneum.[349]

The collaboration with Ludwig brought success: their work on the innervation of the heart and the discovery of the 'depressor nerve' was awarded the first Montyon Prize of the Paris Academy of Sciences for 1867. This investigation clarified the role of the afferent nerves in the visceral nervous system. It showed that stimulation of the central

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[346] See Sechenov's reference to the Academy on Zavarykin's research abroad in Koshtoyants et al, eds, *Nauchnoe nasledstvo*, p. 181

[347] E. Cyon, "Über den Einfluss der Temperaturveränderungen auf Zahl, Dauer und Stärke der Herzschläge," *Arbeiten aus der Physiologischen Anstalt zu Leipzig. Mitgetheilt durch C. Ludwig*, Leipzig, 1866, pp. 77-85

[348] E. Cyon & M. Cyon, "Über die Innervation des Herzens vom Rückenmarke aus," *Cenralbl. F. d. med. Wissensch.* (1866) 51: 389-416; E. Cyon & M. Cyon, "Sur l'innervation du Coeur," *Compt. rend. de l'Acad. d. sc.* (1867) 64: 670-674

[349] E. Cyon, "Über die Wurzeln, durch welche das Rückenmark die Gefässnerven für die Vorderpfote aussendet," *Ber. Sächs. Ges. der Wissensch.* (1868) 20: 104-112; E. Cyon, "Über die Nerven des Peritoneum," *Ber. Sächs. Ges. d. Wiss.* (1868) 20: 119-127

end of the "cardio-sensory" nerve (or the depressor nerve) elicited a reflex reaction as expressed by a sharp drop in blood pressure and dilatation of the blood vessels. A new type of relationship between the heart and the blood vessels came into view: the reflex from the sensory nerves of the heart to the motor nerves of the blood vessels.[350]

Claude Bernard, the chairman of the committee that awarded the Academy of Sciences prizes in experimental physiology in 1867, took a special interest in Cyon's work, which dealt with the conveyance of sensory impulses from the heart and with the mechanism by which the heart can be relieved of too great a load. Bernard's early research had concerned the problem of nervous control of the blood vessels and the temperature change related to it.[351] In 1867 Bernard invited Cyon to work at his laboratory where Cyon continued his research on the effect of the external factors on the functions of the heart, particularly, blood gases.[352] Thereafter Cyon was particularly welcome to work at Bernard's laboratory.

Upon returning to St. Petersburg in 1868, Cyon intended to teach a course of nervous diseases at the Academy. However, his bent for physiological experimentation, his success in the field and his promising reputation in Europe allowed F. V. Ovsiannikov (1827-1906), professor of anatomy and histology, to invite Cyon to the physiological laboratory at St. Petersburg University as an assistant. The University laboratory was a subdivision of the anatomy and histology chair of the department of

[350] E. Cyon & C. Ludwidg, "Die Reflexe eines der sensiblen Nerven des Herzens auf die motorischen der Blutgefässe" ["The Reflex Action of the Sensory Nerves in the Heart on the Motor Nerves of Blood Vessels"], *Ber. Sächs. Gesellsch. d. Wissensch.* (1866) 18: 128-149. On the discovery of the nerve depressor see Schröer, *Carl Ludwig*, pp. 160-162

[351] C. Bernard, "De l'influence du système nerveux grand sympathique sur la chaleur animale," *Comp. rend. Acad. d. Sc.* (1852) 34: 472-75; C. Bernard, "Recherches expérimentales sur le grand sympathique et spécialement sur l'influence que la section de ce nerf exerce sur la chaleur animale," in *Mém. Soc. de biol.* (1853) 5: 77-107; on Bernard's research on vasomotor nerves, see Olmsted, *Claude Bernard*, pp. 81-5

[352] E. Cyon, "De l'influence de l'acide carbonique et de l'oxigène sur le Coeur," *C. r. Acad. Sci.* (1867) 64 (12): 1049-1053

zoology at the physico-mathematical faculty. Ovsiannikov, an experienced histologist, was well acquainted with the work of a physiological laboratory: in the 1860s he had studied under Bernard in Paris. In St. Petersburg University he promoted the idea of a separate space and budget for physiological studies and three years later, in 1866, the University first made a specific allocation of funds for "the establishment and maintenance of a physiological laboratory - 1000 roubles a year."[353]

Ovsiannikov's organizational abilities, his high position as an academician and head of the physiological laboratory at the St. Petersburg Academy of Sciences, as well as his personal connections with state authorities were pivotal at the initial stage of the development of experimental physiology at the University. Being fully aware of the complexity and diversity of the task of physiological training, Ovsiannikov entrusted Cyon with lectures on physiology and practical training, the best choice he could ever have made. Ovsiannikov kept histology for himself,[354] and N. N. Bakst took up a special course on the physiology of the sense organs.[355]

Cyon started his teaching career as a *Privatdozent* and two years later, in 1870, was promoted to a Professor *Extraordinarius.* He took the opportunity to take a five-month leave just after his appointment in 1868 to continue his own research in the laboratories of Vienna, Leipzig, and Paris. By 1869 Ovsiannikov and Cyon had

[353] V. V. Grigor'ev, *Imperatorskii S. Peterburgskii Universitet v techenie pervykh piatideciati let ego sushchestvovaniia [The Imperial St. Petersburg University during the First Fifty Years of its Existence],* St. Petersburg, 1870, pp. 391-4

[354] Ovsiannikov's research interests were concentrated on neurophysiological problems. In Ludwig's laboratory in Leipzig he investigated the action of the vasomotor centers and demonstrated the presence of nerve centers regulating blood pressure in the vessels. His other important research was on the reflex functions of the medulla and spinal cord in the rabbit. See Ph. Owsjannikow, "Die tonischen und reflektorischen Centren der Gefäßnerven," *Ber. d. Sächs. Ges. d. Wiss.* (1871) 23: 21-33; Ph. Owsjannikow, "Über einen Unterschied in den reflektorischen Leistungen des verlängersten und des Rückenmarkes der Kaninchen," *ibid* (1874) 26: 308-318

[355] Nikolai Nikolaevich Bakst (1843-1904) studied under Helmholtz the problem of transmission in the motor nerve in human. The results of his research were presented in his thesis, *O skorosti peredachi razdrazheni po dvigatel'nym nervam cheloveka.* St. Petersburg, 1867

managed to equip the University laboratory with anatomical and physiological instruments and apparatuses to the total sum of 3,124 roubles.[356] That made it possible to accompany lectures with demonstrations, to train students in laboratory technique, and to carry out experimental research. The program involved vivisection, organ isolation, and the application of a variety of physiological devices.

In addition to a wide range of research interests, Cyon was an excellent lecturer and supervisor for students who aimed to specialize in experimental physiology. His lectures at the University were always accompanied by demonstrations of vivisectional experiments in an overcrowded lecture-hall. In a way, his lectures were theatrical performances played to a full house. In the best traditions of scientific public demonstrations Cyon's lectures displayed the importance and power of physiological knowledge and skills to deal with complex functions of a living organism. Cyon was said to be so adroit an operator that sometimes coming into the laboratory on his way to the theater, elegantly dressed in his frock coat and starched white shirt, he could perform experiments without covering his clothes.[357] Pavlov, who was his student at the University and considered himself his disciple, recalled: "Professor I. F. Cyon produced a tremendous impression on us physiologists. We were simply astonished by his masterfully simple account of the most complex physiological questions and his truly artistic ability to perform experiments. You cannot possibly forget such a teacher. I carried out my first physiological experimental work under his guidance."[358]

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[356] Grigor'ev, *Imperatorskii S. Petersburgskii Universitet*, p. 393
[357] W. H. Gantt, *Russian Medicine*. New York, 1937, p. 111; Gantt was an American collaborator in Pavlov's laboratory in 1925-1929
[358] Pavlov, *Avtobiografiia*, in Natochin et al, eds, Pavlov, *Izbrannye trudy*, p. 24; on Cyon and Pavlov see Todes, *Pavlov's Physiological Factory*, pp. 51-52, 55-57

Cyon continued his investigations on innervation of the heart and welcomed students to his laboratory. Pavlov and V. N. Velikii (1851-1911, later a professor of physiology in Tomsk University were the first of Cyon's students not only in his area of research, that is the innervation of the heart, but also in the virtuoso technique of vivisection of warm-blooded animals. Pavlov preserved the best recollection of his teacher and never subscribed to the opinion of Cyon's foes. It was in Cyon's laboratory and under his guidance that Pavlov in collaboration with M. I. Afanas'ev (1850-1910), later a notable pathologist, performed excellent experimental research on the innervation of the pancreatic gland and secretion, which became an overture to a series of famous Pavlovian works on innervation of digestive glands.

After Sechenov had left the Medico-Surgical Academy in 1870, Cyon was regarded as a candidate for the vacancy. At Sechenov's request, Botkin submitted a note to the Conference in which Cyon was presented as an accomplished scholar and teacher deserving the chair.[359] A special commission headed by professor of histology Zavarykin, Cyon's most unappeasable opponent, was to make judgements on the scientific merits of the two candidates, Cyon and Shkliarevskii, extraordinary professor of medical physics from Kiev. Reading the report of the commission which ran to 110 pages, one cannot but be astonished by the sarcastic critique of all twenty-two of Cyon's scientific works submitted to the commission, and by unfair, and at times insulting words about the author, who was accused of "scientific and literary plagiarism, self-conceit, rude polemic means and vulgarity." The report was signed by six professors (F. N. Zavarykin, N. N. Zinin, a pharmacologist I. V. Zabelin (1834-1875), a toxicologist I. M. Sorokin (1833-1917), a physicist P. A. Khelbnikov (1829-1902), and an anatomist

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[359] *Ross. Gos. Voen.-ist. Arkhiv*, fond 316, opis' 38, delo 351, list 4-5, January 1871

V. L. Gruber (1814-1890). The conclusion ran: " In our opinion, it is a sheer impossibility to entrust the scientific supervision of numerous young people entering our Academy to Mr. Cyon."[360] In his turn, professor Balinskii in a special note in 91 pages presented to the Conference a balanced account of Cyon's scientific accomplishments versus the insignificant works of Shkliarevskii, who in Balinskii's opinion could not even qualify for a position.[361] Nevertheless, Cyon was voted down despite the support of Botkin, Ovsiannikov, and Sechenov. In view of the extraordinary situation the Head of the Academy, N. I. Kozlov, appealed to War Minister Milutin, who by his own power appointed Cyon in 1872 professor ordinarius. Milutin's unprecedented decision was based on the recommendations of the leading European physiologists: Bernard, Ludwig, Pflüger, Helmholtz, and Brücke but not on the conclusions of the commission, which he considered unacceptable in scholarly disputes.[362]

Koshtoyants rightly pointed to the political situation in Russia and the responses of the radical press to the case, which became known as the "Cyon affair," and which agitated a considerable part of Russian society. In the atmosphere of the post-reform period and upheaval of the radical movement Cyon's extreme monarchist views, adherence to religious dogmas, firm rejection of any form of radical thought and nihilism were not acceptable. His notoriously reactionary position, which manifested itself in his rejection of Darwinism, and an evident skepticism towards Sechenov's

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[360] "Otchet akademicheskoi komissii: (Professorov Zavarykina, et al) ob uchenykh trudakh Tsiona i Shkliarevskogo," in *Protokoly zasedanii Konferentsii Imperatorskoi Mediko-Khirurgicheskoi Akademii za 1872 god [Proceedings of the Conference of the Imperial Medico-Surgical Academy for 1872]*, St. Petersburg, 1873, pp. 40-150 (122)

[361] "Otchet Professora I. M. Balinskigo ob uchenykh trudakh Tsiona i Shkliarevskogo," ibid, pp. 151-216

[362] Popel'skii, *Istoricheskii ocherk*, pp. 70-4. It might be that the above-mentioned reference letters are preserved in Cyon's archive in Paris.

theory of reflexes of the brain, incited the majority of the professors and students of the Academy against him.[363]

However, there were people other than the notoriously radical students and professors who were afraid that a monarchist Cyon would spoil revolutionary youth. There is no evidence that Zavarykin and other members of the Commission shared the radical views of the students of the Academy. Moreover it is difficult to suspect these professors of sympathy to Sechenov and his mild liberal views. It seems that Cyon's scholarly reputation and his abilities as a teacher were not appreciated or welcomed at the Academy of the 1870s. The atmosphere at the Academy was so tense and critical of Cyon that one would have to possess indeed 'Cyon's nature' to keep on delivering lectures, carrying out experimental work with the students in the laboratory, and pursue his own research. At the same time he continued teaching at the St. Petersburg University. The fact that Cyon was appointed, in spite of the results of voting, roused a new wave of hostility against him. It was Cyon's quarrelsome and unpleasant character, his intolerant and disdainful attitude to his opponents that enhanced non-recognition of his scholarly merits by his colleagues at the Academy.

Cyon's professorship at the Academy (1872-1874), though very short, marked a new period in teaching physiology at the Academy. His laboratory was now housed in the spacious new building of the Anatomical Physiological Institute; the laboratory had been moved from the First Land Forces Hospital to a new building just after Sechenov had left the Academy, in 1871. According to Popel'skii, the lecture-hall for three hundred students was full and so Cyon divided the course into three or four groups. The program of the lectures embraced all areas of contemporary physiology. It started with

[363] Koshtoyants, *Essay*, pp. 160-2

the history of three main trends – anatomical, physical, and physico-vivisectional followed by sections on blood circulation, respiration, digestion, nerve and muscle physiology and sensory organs with the focus on the rich variety of experimental methods applicable to the phenomena under discussion. The important innovation was the introduction of the graphic method and acquaintance with the self-recording devices that made teaching physiology more visual and impressive. Cyon had had a special interest in graphic methods that permitted the particular kind of measurements in his studies on the nerves of the heart and their vasomotor function in Ludwig's laboratory. The method and the analysis of mechanically recorded graphs, introduced by Ludwig in the late 1850s and later widely used for various physiological purposes became the symbol of 'modern physiology' and the notion of exactitude in its practices.[364]

Cyon's lectures, published in two volumes during 1873-1874, became the first original textbook on general physiology in Russia.[365] He dedicated his work to N. I. Kozlov, by then the Chief Medical Inspector at the War Ministry. Kozlov headed the Academy for two years from 1869 but had to leave the post supposedly because of a growing student unrest that irritated the Tsar.[366] As Chief Medical Inspector at the War Ministry, Kozlov took Cyon's side during the struggle with the Academy and presumably interceded for Cyon before Milutin. Moreover Kozlov's support was pivotal for Cyon's activities at the Academy that required substantial funding for the equipment of the laboratory and practical studies for the students and Cyon's own researches.

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[364] On the application of the graphic method by Helmholtz, see Holmes and Olesko, "The Images of Precision: Helmholtz and the Graphical Method in Physiology," in *The Values of Precision*, Wise, ed, pp. 198-221.

[365] I. F. Cyon, *Kurs fiziologii [A Course of Physiology]*, St. Petersburg, v. I, 1873, v. 2, 1874

[366] *Russkii biograficheskii slovar' [Russian Biographical Dictionary]*, St. Petersburg, 1903, v. 4, pp. 53-54.

Within two years, Cyon managed to equip his new laboratory with the best apparatus and instruments available for all areas of experimental physiology. Two rooms of the laboratory were equipped for vivisection work, the third, for blood analysis, the forth, for physiological chemistry. Two other rooms were specially equipped for electrophysiological studies and for studies of sensory organs. The list of apparatus and instruments that Cyon purchased during his four visits to Europe contains 39 pieces of equipment: electrophysiological devices of different modifications, acoustic, vocal, optical instruments, all kinds of recording apparatus such as myograph, sphygmograph, cardiograph, kymograph, and others.[367] Later, in 1876 Cyon published richly illustrated *Methodik* and *Atlas zur Methodik der physiologischen Experimente und Vivisectionen* in which most of the illustrations were pictures of apparatuses collected in the laboratory of the Medico-Surgical Academy. Cyon dedicated that work to Carl Ludwig, "teacher and friend."[368] The *Atlas* is Cyon's best contribution to the history of physiology: it is a unique catalogue of instruments and skillful presentation of experimental methods of nineteenth-century physiology.

Masterful in vivisection of warm-blooded animals and in elegantly executed experiments, unlike Sechenov, Cyon arranged his lecture-demonstrations in all areas of contemporary physiology. In addition to that, he demonstrated the principal physiological experiments in the evening in the form of practical studies, which sometimes lasted till late at night and were popular among students. Cyon devoted much of his time and effort to a practical course of experimental physiology even when there were only two or three students in the laboratory. Apart from lecture-demonstrations for

[367] Popel'skii, *Istorichestkii ocherk*, pp. 81-2
[368] *ibid*, pp. 79-80

the students Cyon, organized a private course for physicians in experimental physiology of respiration and blood circulation. According to Popel'skii, the course was a success and many influential members of St. Petersburg medical establishment attended it.[369]

Judging by the published collection of works carried out in the laboratory in 1873 Cyon's research activities were impressive. The first part of the collection contained seven articles, two by Cyon and the rest by his students. The research objectives were varied: from the investigation on the innervation of the spleen and on the influence of temperature changes on the central ends of heart nerves by I. R. Tarkhanov to the research on innervation of the uterus by M. Shershevskii and from the investigation on vasomotor nerves by M. Polkov to the work on functions of the semilunar ducts by Ia. Solukha. Cyon himself was engaged in the studies on the speed of transmission of excitation along the spinal cord and continued research on reflex mechanisms, his "theory of interference." [370]

In the foreword to the collection Cyon wrote: "The best answer to the attacks directed against my teaching activity would be to publish an account of the research carried out in a short time under my guidance." The second part of the collection entitled "To My Critics" was devoted to the refutation of the conclusion of the commission, which had evaluated his scientific activity: "I am proud that in spite of having been blackballed, I was appointed a professor on the grounds of the references of the first

[369] *ibid*, pp. 80

[370] I. Cyon, *Raboty, sdelannye v fiziologicheskoi laboratorii Imperatorskoi Medico-khirurgicheskoi akademii za 1873 god s prilozheniem kriticheskikh statei professora Tsiona [Works Performed in Physiological laboratory of Imperial Medico-Surgical Academy for 1873 with a supplement of critical articles of Professor Cyon]*, St. Petersburg, 1874, pp. 29-84. E. Cyon, Dr. Solucha, "Über die Funktion der halbcirkelförmigen Kanäle," *Pflügers Arch. ges. Physiol.* (1874) 8: 306-327; E. Cyon, "Über die Fortpflanzungsgeschwindigkeit der Erregung in Rückenmarke," *Bull. Acad. Sci. St.-Petérsb.* (1874) 19 (4): 394-400; E. Cyon, "Zur Lehre von der reflektorischen Erregung der Gefässnerven," *Pflügers Arch.* (1874) 8: 327-340

luminaries of European science."[371] Cyon's caustic attack might well testify to the continuing opposition from the majority of the professors whose routine work contrasted too much with energetic and successful activities of Cyon. Similarly, Sechenov also had experienced covert resistance from his colleagues in the last years of his stay at the Academy.[372]

Cyon left the Academy in 1874 under the pretext of going to Paris. Without going into details, Popel'skii indicated that the real reason was the student unrest and the continuing hostility towards Cyon. Koshtoyants explicitly alluded to the growing radical movement among the students of the Academy.[373] However, a physiologist L. A. Orbeli (1882-1958), Pavlov's coworker, suggested another reason for student unrest, not in politico-ideological terms but in strictly academic: the students appreciated Cyon's lectures highly, but they did not appreciate his high standards at the exam. Orbeli reported (from the words of Pavlov then a student at the Academy) that the conflict between Cyon and the students turned on his strict requirements at the exam, and that led to the students' riots.[374]

Upon resignation from the Academy, Cyon worked in Bernard's laboratory having no position whatsoever, and after Bernard's death in 1878 he saw himself as Bernard's most possible successor. Once again Cyon demonstrated his talent and unflinching capacity for work, as well as his tremendous arrogance. He wrote and defended a thesis and got a doctoral degree in order to be considered for the *concours*.

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[371] I. Cyon, "K moim kriticam" ["To my critics"], in Cyon, *Raboty*, pp. 87-120 (87)
[372] Sechenov, *Autobiographical Notes*, p. 126
[373] Popel'skii, *Istoricheskii ocherk*, pp. 78-79; see also Koshtoyants, *Essays*, pp. 158-160
[374] L. A. Orbeli, *Vospominaniia [Recollections]*, Moscow-Leningrad, 1966; see also Artemov, *Tsion*, pp. 27-8

But this time he was unsuccessful: he left the laboratory blaming Paul Bert for intrigues against him.[375]

His research and teaching career came to an end, but his love of physiology remained. He published in Germany and France a collection of his physiological works, a monograph on the anatomy and physiology of the thyroid gland and the heart, and a monograph on the anatomy and physiology of the nerves of the heart, followed by the researches on the labyrinth of the ear as an organ for mathematical sense of space and time, and on vessels of the glands as regulating protective organs of the central nervous system.[376] All these works were richly illustrated and well produced. Besides, Cyon continued to publish his physiological investigations in *Pflügers Archiv.* A list of his historical, political and financial publications is no less impressive than Cyon's physiological research on a wide range of topics: from Russo-French political and financial relations to the debate on "antireligious policy" of Ministry of Education and Culture headed by Paul Bert, and from social studies on nihilism and anarchism to various aspects of Russian economic and military policy.[377] Cyon later achieved success in a new field (he was engaged in some financial operations in France for the Russian government): the Ministry of Finance, headed by I. A. Vyshnegradski (1831-1895), a

[375] Élie de Cyon, *Recherches expérimentales sur les fonctions des canaux semi-circulaires et sur leur rôle dans formation de la Notion de l'Espace.* Thèse pour le Doctorat en Médicine à la Faculté de Médicine, 1 Avril 1878. Paris, 1878. Cyon gave a short comment on Bert's role in his decision to leave the laboratory. See in Cyon, *Die Gefässdrüsen*, p. 364. On the ideological debate between Cyon and Paul Bert see, G. E. Feldman *Paul Bert*, Moscow, 1979, pp. 32-34 (in Russian).

[376] E. von Cyon, *Gesammelte physiologische Arbeiten.* Berlin, 1888; E. von Cyon, *Beiträge zur Physiologie der Schilddrüse and des Herzens.* Bonn, 1898; Élie de Cyon, *Les nerfs du coeur. Anatomie et physiologie*, Paris, 1905; E. von Cyon, *Das Ohrlabyrinth als Organ der mathematischen Sinne für Raum und Zeit. Den Manen von J. P. M. Flourens, E. H. Weber und K. Vierordt gewidmet. Mit 45 Textfiguren, 5 Tafeln und dem Bildnis des Verfassers*, Berlin, 1908; E. von Cyon, *Die Gefässdrüsen als regulatorische Schutzorgane des Zentralnervensystems*, Berlin, 1910

[377] See "Historische, politische und finanzwissenschaftliche Schriften," in E. von Cyon, *Die Gefässdrüssen*, pp. 369-71

notable scholar and mechanic engineer, granted Cyon the rank of Active Councilor of State carrying the entitlement to noble rank.[378]

However, Cyon's contribution to the introduction of the laboratory to Russian medicine is of remarkable importance. His work at the Academy embodied an integrative approach to teaching physiology at the Academy: graphic methods in representation of physiological phenomena, vivisectional techniques, equipment of the laboratory to carry out research in practically all areas of modern physiology. The important innovations made during Cyon's short stay at the Academy were a wider range of research projects carried out in his laboratory, lecture-demonstrations with the application of complex vivisectional methods, and finally the introduction of systematic training practice of students in the techniques of experimental research, following the example of Ludwig's Institute in Leipzig. Cyon successfully promoted the discipline: in a number of publications he stressed the importance of experimental methods, techniques and instrumentation in the work of a scientifically trained physician. His *Atlas* (1876) was designed specifically as a source book of current methods and instrumentation used in practically all areas of experimental physiology. In Cyon's time physiology as a well-defined and established discipline at the Academy was practiced in a spacious excellently equipped laboratory in a new building thus representing the growing change from a small poorly equipped laboratory for a few selected students to the laboratory of increasing size with adequate sophisticated instrumentation for systematic training and research of a larger number of students. Due to his efforts and to the promotion of research work done during his professorship, the Academy's laboratory

[378] A short account on Cyon as a journalist, see in Shtraikh, ed, *Bor'ba za nauku*, pp. 61-2; see also Artemov, *Tsion*, pp. 33-44

was ranked among the best physiological institutions in Europe. Bernard in his introductory lecture at the Museum of Natural History in Paris in 1877 spoke highly about "the splendid physiological institute in St. Petersburg." It was obviously the laboratory at the Medico-Surgical Academy that Bernard meant: "...physiology and experimental medicine are housed in spacious institutions in Germany and Russia."[379] And in that evaluation of Russia's first and most successful Physiological Institute Cyon's contribution was indispensable.

[379] K. Bernard, transl., M. A. Antonovich, *Zhiznennye iavleniia, obshchie zhivotnym i rasteniiam. Lektsii, chitannye v Muzee estestvennoi istorii v Parizhe [Life Phenomena, Common in Animals and Plants. Lectures delivered at the Museum of Natural History in Paris]*, St. Petersburg, 1878, p. 9

...mais les sujets ne s'improvisent dans la science; s'ils éclatent parfois comme la lumière, dans les découvertes, c'est par des faits qu'il faut bien posément et bien consciencieusement constater, avant de s'y fier.

Georges Sand, *Valvèrde.* From Mendeleev's *Dnevnik* 1861 [380]

[...but the subjects in science are not improvised; if they explode sometimes like light in discoveries, it is through facts which must be established steadily and conscientiously before you can rely on them.]

[380] Vavilov et al, eds, *Nauchnoe nasledstvo,* p. 111

Chapter III

From Physics and Chemistry of the Body to Physical Chemistry: Sechenov's Research on Blood Gases and Salt Solutions

After ten years of work at the specialized elite institution under the aegis of the War Ministry, Sechenov started his career anew in the university system. He had left St. Petersburg, the most attractive scientific center in Russia, and his laboratory, the most reputable institution for experimental physiology that he had created. He had changed his secure position of ordinary professor and declined possible promotion to a higher rank of Active Councilor of State (a civil rank corresponding to the military rank of Major-General). He had resigned from the Medico-Surgical Academy in chagrin, following a change in management that left him exposed to a new group of men who did not respect his scientific judgment. They had not wished to appoint the candidates he backed, nor the successor he suggested.

Sechenov's new career began at the provincial Novorossiisk University in Odessa, and then shifted again to St. Petersburg, now to the University, by then the leading scientific and educational center in Russia. His career during this period reflects the ways of general development of experimental physiology and the physiological laboratory in particular. Before examining Sechenov's research and pedagogical activities at both Universities, it is useful to discuss briefly the state of Russian Universities in the sea of change during the two distinct periods: the beginning of the reform era in the early 1860s and the post reform period a decade later.

The discussion begins with the quotation from the speech of A. S. Norov, Minister of Education, at Kazan University in the fall of 1855 – the time of the severe defeat of the Russian army at the Crimean front: "We have always regarded science as an essential necessity, and now we regard it as our first need. If our enemies are superior to us, they owe their advantage solely to the power of their education."[381] The quotation clearly states the government's awareness of Russia's backwardness in science and technology and its willingness to modernize educational system to meet new economic, military, and social demands.

The crucial step in the educational reforms that followed the Crimean War was the new University Statute of 1863. The Statute incorporated the ideas of a select group of leading intellectuals, such as Pirogov, and gave the universities corporate rights and the status of a special community with a wide range of independent action. A university council of professors was now responsible for the organization of scientific research and teaching programs. It also played an important role in the preparation of university budgets and in university appointments and promotions. Finally, a council had now full control of university publications and selection of students for studies in foreign universities to prepare for academic careers at home. Furthermore, the new Statute authorized the universities to divide their faculties into departments, which was conducive to rapid growth of specialization in academic training and the expansion of the university curriculum, particularly in the physics and mathematical faculties. On the whole, as Vucinich has pointed out, the 1863 statute, and intellectual upsurge that insured it, helped the universities become the foremost centers of scientific investigation

[381] The classical treatment of educational reforms in Russia is found in Vucinich, *Science in Russian Culture*, v. 2, pp. 35-65 (36). One of the best discussions on the university reform and the post-Reform era in Russian is Eimontova, *Russkie universitety*, pp. 78-92

in Russia, a position that had been previously been occupied by the St. Petersburg Academy of Sciences.[382]

However, although by the end of 1860s the government began to help the universities expand their research facilities, the instruments, working space, and technical staffs of the laboratories in the Russian universities were still no match for the experimental laboratories in Europe. The systematic expansion of individual laboratories at St. Petersburg University, even for such scholars as Mendeleev and Butlerov, was seriously hampered by budgetary uncertainties. S. P. Botkin wrote: "In Berlin I realized clearly the difficult status of a scientist in Russia, how isolated we are over there. Everyone is left to his own powers. This trip convinced me of the necessity to go abroad at least once a year, or one can fade and become capable of nothing."[383]

Apart from that, the lack of adequate research institutions for academic training and the pressing need to fill in new teaching position at the universities necessitated the Ministry of Education sending selected students for advanced studies at the leading West European Universities, as the Ministry of War had already done. Sechenov in his popular article in *Vestnik Evropy* remarked that half of the Russian professors engaged in teaching the natural sciences in the early 1880s were those who had studied in Europe during the late 1850s and early 1860s.[384] Furthermore, the recommendations, contacts and reputation of the Russian scholars of the first wave of the scientific move towards the West such as Mendeleev, Butlerov, Borodin, Botkin, and Sechenov were of particular importance for their students in having access to the best research institutions

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[382] Vucinich, *Science in Russian Culture*, v. 2, p. 51
[383] Belogolovyi, *S. P. Botkin*, p. 38
[384] I. M. Sechenov, "Nauchnaia deiatel'nost' russkikh universitetov po estestvoznaniiu za poslednee dvadtsatiletie" ["Scientific Activities in Natural Sciences at Russian Universities for the Last Twenty Years"], in *Vestnik Evropy [Messenger of Europe]* (1883) 11: 330-342 (334)

of Europe and also for maintaining and strengthening the connections with European scientific community.

After the attempt on Alexander II's life by Moscow University student D. Karakozov in 1866, the universities were under constant pressure from an oppressive government reaction that had become inescapable. Official return to educational conservatism was best manifested by the activities of the newly appointed Minister of Education, Count D. A. Tolstoi (1823-89), who was convinced that university autonomy undermined autocratic ideology. Sechenov wrote about this time: "It is known that in the 70s, the government reaction against anarchistic terror reached its climax and was expressed in part by a whole series of extremely severe administrative-police influences on the life of the students."[385]

The political unrest of the 1870s at the universities overshadowed the successes in research and training pursued by many renowned university scholars. In his article Sechenov pointed to the wide range of scientific activities in Russian universities and to the growth of Russian science between 1860s and early 1880s. These represented the final phase in Westernization of Russia, a process that was elevated to new heights by his colleagues, notably chemists, physiologists, and mathematicians who had "introduced Russia to the family of enlightened nations." At the same time, Sechenov had to admit that despite notable achievements, the scientific work of the 1870s did not emulate either the pioneering zeal or the theoretical depth of that produced during the 1860s.[386]

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[385] Sechenov, *Autobiographical Notes*, p. 143

[386] Sechenov, "Nauchnaia deiatel'nost'," p. 342; see also Vucinich, *Science in Russian Culture*, v. 2, p. 64 and Eimontova, *Russkie universitety*, p. 99

The following chapter examines Sechenov's successive research and teaching within the university system from 1871 to 1888. We look first at his activities in setting up his second laboratory for experimental physiology, at Novorossiisk University, and then follow Sechenov to his third laboratory, at St. Petersburg University, focusing on his research objectives and means to pursue these objectives. Sechenov's significant investigations on blood gases and salt solution within broader scientific context in both experimental physiology and physical chemistry will be discussed separately.

1. Move to Odessa: the Laboratory at Novorossiisk University

Sechenov's move to Novorossiisk University coincided with the shift in his research objectives from problems related to physiology of the nervous system to the blood gas researches, which he had started in 1857 in Ludwig's laboratory in Vienna. The revival of Sechenov's interest in physico-chemical problems might be well explained by the influence of Mendeleev in whose laboratory at the St. Petersburg University Sechenov worked for some time before leaving St. Petersburg for Novorossiisk. In this regard he wrote to Mechnikov: "In two weeks I finish my lectures at the Academy and move to Mendeleev's laboratory to study chemistry. ...Possibly I will stay here for a year. ...Then I would have one more tool to struggle for my existence in the rank of professor."[387]

By that time Ilia Mechnikov had got a professorship in zoology at Novorossiisk University. He succeeded in soliciting before the Council of the physico-mathematical

[387] Sechenov to Mechnikov, letter d. St. Petersburg, 24 November 1870, in Shtraikh, ed, *Bor'ba za nauku*, p. 71

faculty for Sechenov's appointment as an ordinary professor at the zoology department. In his petition to the University Council, Mechnikov particularly stressed that there was no chair of physiology at the University, but the department of zoology had the premises and the funding necessary to organize a physiological laboratory and it needed a professor: "In Sechenov, the University would have an excellent teacher and a distinguished scientist."[388]

The Council of the faculty and Rector of the University F. I. Leontovich were willing to accept Sechenov, but Minister of Education Count D. A. Tolstoi was reluctant to approve the appointment. Soviet historians of medicine rightly point out that the reason for the delay in Sechenov's appointment was not the insufficiency of funds for a new position of an ordinary professor; it was Sechenov's reputation as a 'thorough materialist' that so frightened the officials at the Ministry of Education.[389] According to Sechenov, his appointment finally went through due to the intervention of the Head of the Medical Department in the Ministry of Internal Affairs, E. V. Pelikan, who was well acquainted with Sechenov and obviously appreciated his scientific merits. Sechenov himself remarked with sarcasm: "I kept very quiet: in two years I did not lead a single student astray, did not provoke a single rebellion, did not construct barricades. I so delighted the trustee who went to bail for me that he made me an Active Councillor of State. ... Apparently he continued to testify before the high authorities to my loyalty

[388] Koshtoyants et al, eds, *Nauchnoe nasledstvo*, pp. 103-4

[389] I. D. Delianov, one of the high officials of the Ministry of Education, in his confidential letter to the Trustee of Odessa District S. P. Golubtsov, expressed his fear regarding Sechenov's possible harmful effect on the students, see Koshtoyants et al, eds, *Nauchnoe nasledstvo*, pp. 105-6; for overview on Soviet historiography on this question, see F. N. Serkov, "Odesskii period nauchnoi i obshchestvennoi deiatel'nosti Sechenova" [" Odessa Period in Scientific and Social Activity of Sechenov"] in Kostiuk et al, eds, *Sechenov*, pp. 134-42

during the following years."[390]

In the fall of 1871 Sechenov started his work at the University. As an experienced scholar, he knew very well the kind of laboratory basis he needed to organize experimental research in a new place: physical premises, equipment, supplies, an independent budget and an assistant to carry out experimental work. Sechenov's letters from St. Petersburg to Mechnikov in Odessa convey a kind of uneasiness regarding the difficulties he foresaw in setting up a new laboratory in a remote provincial university in southern Russia. Again and again his major concern was apparatus and instruments: purchasing and adjustment or sometimes making various devices from any accessible means at each new center, was typical for the spread of that type of physiology Sechenov was engaged in:

> I need to know as soon as possible: the appropriation for purchasing equipment for the laboratory, the annual budget for research purposes, and the availability of a position for my assistant P. A. Spiro for at least 400 roubles... Has gas equipment been installed in the the laboratory? Presence of my assistant here is utterly necessary for me. He is skillful and with his help I can make a lot of simple devices which, while we are without necessary instruments, would be of great importance.[391]

The budget of the small university was nothing like that of the Medico-Surgical Academy. Sechenov was aware that he could not rely on the kind of financial support that he had during the early years of his stay at the Academy. Nevertheless, his new laboratory got a budget of 672 roubles, 2000 roubles were granted for the purchase of the research tools and 500 roubles for Sechenov to move from St. Petersburg to Odessa (that money he spent on laboratory equipment).[392] The spacious rooms for the new

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[390] Sechenov, *Autobiographical Notes*, p. 135

[391] Sechenov to Mechnikov, letter d. St. Petersburg, 26 October 1870, in Shtraikh, ed, *Borba za nauku*, pp. 69-70

[392] Koshtoyants et al, eds, *Nauchnoe nasledstvo*, p. 110

laboratory were not adapted for experimental work, so for the first few months Sechenov together with his assistant was occupied with adjusting and assembling various devices and with other organizational and technical matters. Although the budget seemed relatively reasonable, Sechenov realized how difficult it would be to set up new research and teaching facilities and keep them in working order: "Suppose that I spend all the money [600 roubles a year] exclusively on instruments for the laboratory, not spending anything on the lectures, my own work and work with the students, even then I would need 10 years to equip my laboratory properly, taking into account that every small thing has to be ordered from elsewhere."[393]

At the same time, Sechenov was certain that he could arrange a laboratory even with modest means to pursue research and practical training in a limited range of experimental problems. He was well acquainted with the main workshops for physiological instrumentation in Germany and Austria, and already had experience in ordering, purchasing, and possible problems during packing and transportation of instruments from abroad. He wrote from Vienna (July, 1871) to the Council of the University asking for permission to order the following equipment for his laboratory: [394]

	Maker	Price (thaler/gulden)
Set of electrophysiological devices	Sauerwald (Berlin)	300
Glassware	Gräner & Fridrichsen (Tübingen)	300
Instruments for haemodymamics and vivisection	Schortmann (Leipzig)	65

[393] Sechenov to Mechnikov, letter d. St. Petersburg, 12 October 1870, in Shtraikh, ed, *Bor'ba za nauku*, p. 68

[394] Koshtoyants et al, eds, *Nauchnoe nasledstvo*, pp. 109-110. In that list of instruments Sechenov indicated not only prices but also the makers and their addresses.

2 chemical balances	Rüprecht (Vienna)	725
Anatomical instruments	Abservorst (Vienna)	135
3 induction apparatus	Meyer & Wolf (Vienna)	130
Porcelain /metal dishes, air pumps, spectroscope, small laboratory equipment	Lenoir (Vienna)	1,070

As previously at the Academy, Sechenov equipped the new laboratory in accordance with his teaching program and research objectives in two areas: electrophysiology and blood gas studies. Considering the poor condition of the remote university, he managed to create comparatively favorable conditions for his individual research and for teaching. A standard set of electrophyiological devices was indispensable for lecture-demonstrations and for practical training of the students, these two important innovations that Sechenov introduced into the teaching program at Odessa University. As in the Academy, Sechenov spent all his time at the laboratory, alone or with his assistant Spiro. Sometimes he worked together with Mechnikov. Mechnikov had been fascinated with Sechenov's experiments related to the central nervous system since 1868 during his visit to Sechenov in Graz. Now, they collaborated in performing a series of experiments on the influence of the vagus nerve on the heart, and demonstrated that the fibers of the vagus, which inhibited the action of the heart, ended in the nervous centers of the heart in the same manner as afferent fibers.[395]

The centerpiece of Sechenov's experimental work in Odessa was the study of the state of carbon dioxide in the blood. For that he needed to set up absorptiometric devices in the poor conditions of the provincial workshops: a mechanic prepared, according to Sechenov's instructions, metal parts for the apparatus; the glass parts Sechenov made

[395] I. Setchenow, I. Metschnikoff, "Zur Lehre über die Vaguswirkung auf das Herz," *Zbl. med. Wiss.* (1873) 11 (11): 163-71

himself since there was no glassblower in Odessa.[396] The technical arrangements for the experiments with the 'absorptiometer,' a bulky apparatus with tubes connected to reservoirs of mercury demanded a great deal of technical skill and experience in the conditions of a new laboratory as well as much time and effort. Sechenov's absorptiometric studies in Odessa flowed directly from his earlier blood gas research. His perceptive insights in the investigation of the blood as physicochemical system actually emerged from a deeper and different understanding of his previous researches and their relation to similar work carried out elsewhere, particularly in Germany. The results of his absorptiometric work were published primarily in German journal and reported at the meetings of the Novorossiisk Natural Scientists Society that will be discussed separately.

In Odessa Sechenov undertook the translation of two contemporary German textbooks, one by Otto Funke and the other by Ludimar Hermann.[397] The choice reflected Sechenov's research interests: Funke's textbook had attracted his attention as early as 1857 during his studies in Funke's laboratory in Leipzig. The textbook contained a detailed account of the exiting experimental technique used in the studies of physico-chemical properties of the blood, including Funke's innovative methods for crystallization of the blood, accompanied by a fine atlas of coloured pictures of various blood crystals. Sechenov seemed to value particularly the experimental part of the textbooks that helped to convey the technical content of German physiology to the

[396] Sechenov, *Autobiographical Notes*, p. 130
[397] O. Funke, *Lehrbuch der Physiologie*, Leipzig, 1857; O. Funke, I. M. Sechenov, ed., *Uchebnik fiziologii [Textbook of Physiology]*, St. Petersburg, Part 1, 1872; Part 2, 1873; L. Hermann, I. M. Sechenov, ed., *Osnovy fiziologii cheloveka [Principles of Human Physiology]*, I ed. – 1873, 2 ed. in 1875. Funke was interested in the problems of physico-chemical properties of the blood: in 1851 he found hemoglobin in the blood of the spleen. O. Funke, "Über das Milzvenenblut," *Z. rat. Med.* (1851) 1: 172- 9; idem, "Neue Beobachtungen über die Kristalle des Melzvenen-und Fisch-Blutes," *Z. rat. Med.* (1852) 2 : 198-207

Russian audience. In its turn, Hermann's *Grundriss* was a comprehensive and clear statement of the fundamental principles of experimental physiology. The *Grundriss* presented a detailed account of blood gas research in Germany. It also included a discussion of Sechenov' studies in the field which were widely accepted among German physiologists, engaged in the problems of respiratory functions of the blood. Similarly, Felix Hoppe-Seyler and Willy Kühne, the leading physiological chemists of the time, referred in detail to Sechenov's blood gas researches in their textbooks.[398]

In Russia, however, Sechenov was viewed from a different angle. His deviations from his laboratory matters into philosophical issues connected with his attempts to work out psychological problems on a strictly physiological basis were not appreciated by academic or by literary circles for whom the eternal question of mind and body lay beyond scientific explanation, physiological in particular. Sechenov's polemics on the task of psychology with K. D. Kavelin (1818-85), the well-known liberal, historian and publicist, aroused a new wave of irritation in certain literary intellectual circles.[399] F. M. Dostoevskii's comment is particular telling in this respect:

> It is not the same in Europe; there you can meet Humboldt and Bernard and other such people with universal ideas, with tremendous education and knowledge not only in their own specialty. In our country, however, even very gifted people, for instance, Sechenov, are basically ignorant persons and uneducated outside of their own subject. Sechenov knows nothing about his opponents (the philosophers), and thus he does more harm than good with his scientific conclusions. As for the majority of students, male or female, they are an

[398] L. Hermann, *Grundriss der Physiologie des Menschen*, Berlin, 1874, pp. 42-7; W. Kühne, *Lehrbuch der physiologischen Chemie*, Leipzig, 1875, pp. 225-33; F. Hoppe-Seyler, *Physiologische Chemie*, Berlin, 1877, pp. 377-99

[399] I. M. Sechenov, "Zamechaniia na knigu g, Kavelina *Zadachi psichologii,*" ["Notes on Mr. Kavelin's book *The Problems of Psychology*], in *Vestnik Evropy*, (1872) 11: 386-420; on Sechenov's psychological views, see A. A. Smirnov, "Psikhologicheskie vozzreniia Sechenova," in Kostiuk et al. eds, *Sechenov*, pp. 413-47. Literature on his subject is rather extensive. I refer to this article as a kind of typical generalization of the issue.

ignorant lot. What is the benefit in this for mankind?[400]

Later in his *Notes* Sechenov remarked as if answering all kinds of harsh reproaches, that although he was made out to be a nihilist philosopher because of the little book [*Reflexes of the Brain*] he had not heard, during the forty years since its appearance in print, "of a single instance, thank heavens, in which it had moved anyone to evil because of a false understanding of its points."[401]

Interestingly, Sechenov's philosophic deviations were not taken very seriously by many of his colleagues, who justly valued his experimental research. However, in general, his contributions as a laboratory scientist were frequently overshadowed by some of his popular writings. The physiological community in Russia was not large; there was no specialized society for physiology and no specialized journals; the few rather small physiological laboratories were poorly staffed and funded. Sechenov belonged to the first generation of Russian experimental physiologists closely connected to the European scientific community. It was among the German physiologists that Sechenov, one of the most successful students of Ludwig, enjoyed a deserved reputation for his experimental researches on central nervous inhibition (without its materialistic and ideological consequences) and his work on blood gases. There was an appreciation of the exactness of the results he had got, and refinement of the method and apparatus he had achieved, the two major virtues of an experimental physiologist of the new generation.

Sechenov preserved the most pleasant recollections of Odessa, a 'nice half-European city,' and its University for a circle of good friends: his assistant P. A. Spiro, a

[400] F. M. Dostoevskii to A. F. Gerasimova, letter d. St. Petersburg, March 1877, cited in Koshtoyants, *Essays*, p. 170
[401] Sechenov, *Autobiographical Notes*, p. 111

distinguished zoologist A. O. Kovalevskii, a physicist N. A. Umov, and particularly Ilia Mechnikov: "Of all the young people I have known, I have never in my life met a more fascinating person than Ilia Ilich Mechnikov, by the liveliness of his mind, his inexhaustible wit and his well-rounded education. He was so serious and productive in science. At that time he had done a great deal in zoology and he had made a great name for himself in it."[402] Being close friends, they sincerely shared personal and scientific successes, failures and aspirations, as well as their research plans and problems. Sechenov's letters to Mechnikov offer an insight into the intellectual milieu of nineteenth century Russian science including observations on academic life, appointments, patronage, characteristics of their colleagues, and inevitably reveal Sechenov's deep compassion for Mechnikov's personal hardships.

Sechenov never abandoned the idea of moving back to St. Petersburg. In 1875 when Cyon resigned from the Academy and the University, Sechenov asked Mendeleev and Ovsiannikov to solicit for him before the Council of the St. Petersburg University. He wrote to Mendeleev: "...taking into account the type of my present research it is extremely important for me to be near you and in St. Petersburg where the means and conditions for my work are incomparably better than here. ...With your help I could probably work successfully now in physiological chemistry as I have already many important problems in hand."[403]

The centralization of Russian science was responsible for concentration of the best research facilities and big and rich libraries in St. Petersburg. Creation of the physiological laboratory at Novorossiisk University in 1870 reflected the growing

[402] Sechenov, *Autobiographical Notes*. p. 132
[403] Sechenov to Mendeleev, letter d. Odessa, March 1875, in Koshtoyants et al, eds, *Nauchnoe nasledstvo*, p. 220-1

determination of Ministry of Education to expand modern research and teaching facilities in the university system. Eitmontova has pointed out that in 1869 Count Tolstoi strongly recommended to university councils to work out measures to engage students in serious research. Aiming at keeping students and instructors away from political activities, Tolstoi's recommendation was conducive to increasing governmental assistance to establish and maintain laboratory and research facilities.[404] However, the provincial universities were too weak to undertake the task, which required substantial funding and support from the governmental structures. Their remoteness from the capital, continuous lack of funds, bureaucratic impediments, and dependence on the central government only added to the poor state of the provincial universities and hampered the development of university science. Besides, the scientific milieu of a provincial university was no match to that of the capital. According to Mechnikov, the intellectual atmosphere in Odessa was stifling and depressing and abounded in petty academic intrigues.[405]

Under these conditions young scientists could not possibly get sufficient training and start independent research. In his last official report to the Council of the physico-mathematical faculty of Novorossiisk University Sechenov expressed his concern about the fact that adequate physiological training was still available only in Western laboratories:

> For those who study physiology the most important laboratories for the present are: Hoppe-Seyler's in Strasbourg, Donders's in Utrecht,[406] and Ludwig's in Leipzig. In the first, studies in chemistry are systematized; in the second - more than anywhere else it is possible

[404] Eimontova, *Russkie universitety*, pp. 85-7
[405] Mechnikov, *Stranitsy vospominanii*, pp. 77-86
[406] Franciscus Cornelius Donders (1818-1889) was well known for his research in physiological optics, as well as the negative pressure in the intrapleural space and the velocity of psychic processes. R. ter Laage, "F. C. Donders," in *Dict. Scient. Biogr.* v. 4, pp. 162-4

to learn accurate physical methods of research in the animal organism; about significance of the third, it is needless to speak, as its reputation is known all over the world. Study in all three laboratories is desirable, in the first and last it is a necessity.[407]

Fortunately for Sechenov, during his visit to Novorossiisk University in 1875 Minister of Education Count Tolstoi expressed a favorable disposition towards to the willful professor. Next year Sechenov was transferred to St. Petersburg University without delays and bureaucratic impediment. There are two main consequences of Sechenov's move to Odessa. Here he managed to arrange a new center for experimental physiology, and trained an independent scholar, P. A. Spiro (1844-1893), who succeeded him at the laboratory. Later, another of Sechenov's students from St. Petersburg University, the notable physiologist B. F. Verigo (1860-1925), headed the chair of physiology at Novorossiisk University. Both continued the investigations started by Sechenov in the field of respiratory and nerve-muscle physiology. The second implication is the transition in Sechenov's research from physics and chemistry of the respiratory function to the investigation of the nature of salt solution, one of the important problems in nineteenth-century physical chemistry, which was brought about by the increasing complexity of his insightful study on the blood as a physico-chemical system.

2. Back in St. Petersburg: the Laboratory at the University

Sechenov spent only five years in Odessa. In the fall of 1876 he returned to St. Petersburg, this time to the University where he had obtained the teaching post he

[407] Koshtoyants et al, eds, *Nauchnoe nasledstvo*, p. 113

sought. The University's laboratory, founded by Ovsiannikov and Cyon in 1866, was in a poor state after Cyon had resigned from both the Medico-Surgical Academy and the University in 1874 and left for Paris, and Ovsiannikov was too busy in his laboratory at the St. Petersburg Academy of Sciences to take care of the University's laboratory. Now Sechenov was faced with the task of re-organizing the laboratory according to his teaching and research program, for the third time again from scratch, as the poor old laboratory equipment had been neglected for nearly two years. Besides insufficient funding of the university's research and laboratory facilities and structural and organizational obstacles within the University system did not leave any hope to improve the situation. Sechenov related his first impressions about his new laboratory to Mechnikov:

> The space I have is much worse then yours [at Novorossiisk University], only two rooms without any equipment for my work. But little by little I borrowed some things from other laboratories and some things I bought on credit, and now everything is arranged. I can continue to pump CO_2 with interruptions though, because of inability of the servants. They all, of course, are soldiers who stand at attention and are coached to stretch the poor dogs on the table at the first nod. Fortunately, I have found an able assistant at the laboratory, and he helps me a great deal. ...Thanks to him I can teach without any difficulties and in this respect I am very pleased.[408]

In a month, he wrote: "I am every day at the laboratory, but for my work I do nothing because here fixing of a screw takes a week (no exaggeration). And if it was not for my students whom I teach what I can, it would make me sick. ... Due to this inactivity I read much. ... After all it might be better, I have a rest from long pumping.[409]

[408] Sechenov to Mechnikov, letter d. St. Petersburg, 19 September 1876, in Shtraikh, ed, *Bor'ba za nauku*, p. 87
[409] Sechenov to Mechnikov, letter d. St. Petersburg, 2 November 1876, in *ibid*, p. 88

The influential Ovsiannikov, experienced in administrative matters, requested from the Council of the physico-mathematical faculty "additional funds from any source, at least 1000 roubles, for the physiological laboratory." A petition, submitted by Sechenov and himself from September 16, 1876 runs: "The laboratory is in great need of equipment for the work on chemical problems. It lacks the glassware, reagents, and the most commonly used working and measuring tools. Their acquisition is a pressing necessity whereas the budget of the laboratory (1000 roubles on anatomy and physiology) does not allow such a completion."[410]

This repeated re-starting of the laboratory demonstrates the importance of equipment and instruments for the new style physiology. It also allows us to feel Sechenov's frustration at interrupting the flow of his work to deal with the repeated organizational problems. Year by year in the annual accounts on the work of the physiological laboratory submitted to the Council of the University, Sechenov continued to report on unsatisfactory conditions in the laboratory, particularly the lack of adequate equipment and instruments, so essential to the kind of research he was pursuing and to his method of teaching physiology: "The successes of the practical studies on physiology are poor for the following three reasons: 1) extremely limited annual budget of the laboratory, 2) lack of instrumental appliances, 3) lack of space in the laboratory The space and means of the physiological laboratory, unfortunately, do not allow us to teach more than ten students in the laboratory." In his formal appeal to the Council of the University from September 9, 1886 he wrote:

> In view of the fact that, according to the new University Regulations, practical training in all scientific disciplines including physiology is mandatory, and that the number of students,

[410] Koshtoyants et al, eds, *Nauchnoe nasledstvo*, p. 119

> registered for the practical courses in chemical and physical areas of physiology, exceed the number of students who can be trained in the laboratory, I suggest enlarging the space for the laboratory by least one room and also to increase the annual budget of the laboratory by 500 roubles to cover the expenditures for materials, preparations and apparatus necessary for practical training.[411]

Sechenov's efforts to improve the financial situation and the structural independence of the physiological laboratory eventually proved successful, although the bureaucratic wheels turned slowly. The result, supported further by yet another of Sechenov's requests and a new program on physiological training in 1887, was an independent physiological laboratory with a special budget in 1888.[412]

A. A. Ukhtomskii, professor of physiology at St. Petersburg-Leningrad University, pointed out that Sechenov belonged to the physico-mathematical department first at Novorossiisk and then at St. Petersburg University not only by name but also by the nature of his experimental research. Sechenov established a physiological specialty at the University in coordination with physico-chemical disciplines. Physiology at the university's natural sciences department, according to the established medical tradition, had been taught in the first two years. Sechenov suggested that physiology be taught in the third and forth years not as a propaedeutic discipline, but as a discipline that crowned the training of a natural scientist. Ukhtomskii stressed that Ovsiannikov and Cyon laid the foundation for the development of experimental physiology at the University's natural sciences department that later with Sechenov and Vvedenskii led to the emergence of a distinct school in Russian neurophysiology.[413] Ukhtomskii further

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[411] *ibid,* pp. 122-124, 127-128
[412] *ibid*, p. 133
[413] A. A. Ukhtomskii, "I. M. Sechenov v Peterburgskom-Leningradskom universitete" ["I. M. Sechenov in St. Petersburg-*Leningrad* University], in *Fiziologicheskii Zhurnal SSSR [Journal of Physiology of the SSSR]* (1954) 40 (5): 527-539 (532, 538). Gustav Heirich Wiedemann (1826-1899), a student of Gustav Magnus, professor of

argued that electrophysiology, though of a particular interest for Sechenov, did not occupy a consistent and prolonged period in his experimental work:

> Why so? For all the profundity and thoroughness of Sechenov's scientific work the reasons for that did not lie in his power. With the electrotechnical resources and devices which were available here it was impossible to go far; and with surprise we note that, nevertheless, I. M. Sechenov with the help of a Wiedemann galvanometer managed to make a discovery which became the beginning of the electrophysiology of nervous centers.[414]

Indeed, Sechenov mentioned his electrophysiological investigations to Mechnikov: "The laboratory means are as insignificant as those in Odessa, but fortunately I am engaged in researches which require little expense; that is why poverty is not a burden to me."[415] Being engaged consistently and deeply in absorptiometric investigations and research on chemical dynamics of solutions, Sechenov, nonetheless, supervised research work of his students that was mainly related to neurophysiological problems. Professor F. E. Tur recollected:

> The only person who assisted Sechenov in his absorptiometric studies was an attendant Osip Kukharenko. Every morning Ivan Mikhailovich came to the laboratory and in a low voice called: "Osip!" Osip at once left everything and they started working in Sechenov's room. Sechenov's students in the laboratory were given neurophysiological and, partly, electrophysiological tasks.[416]

Only once during that period did Sechenov interrupt his absorptiometric research: in 1879 he started his "galvanic researches" which lasted two and a half years: "... I have left entirely, for the present, experiments on respiration, now I am working on the electrical properties of the central nervous masses. Something great seems to have

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physics at various German universities, ultimately in Leipzig, was known for his widely used model of galvanometer.

[414] Ukhtomskii, "Sechenov v Peterburgskom universitete," p. 528

[415] Sechenov to Mechnikov, letter d. 2 Feb. 1880, cited in Shtraikh, ed, *Bor'ba za nauku*, p. 103

[416] Ukhtomskii, "Sechenov v Petersburgskom universitete," p. 534

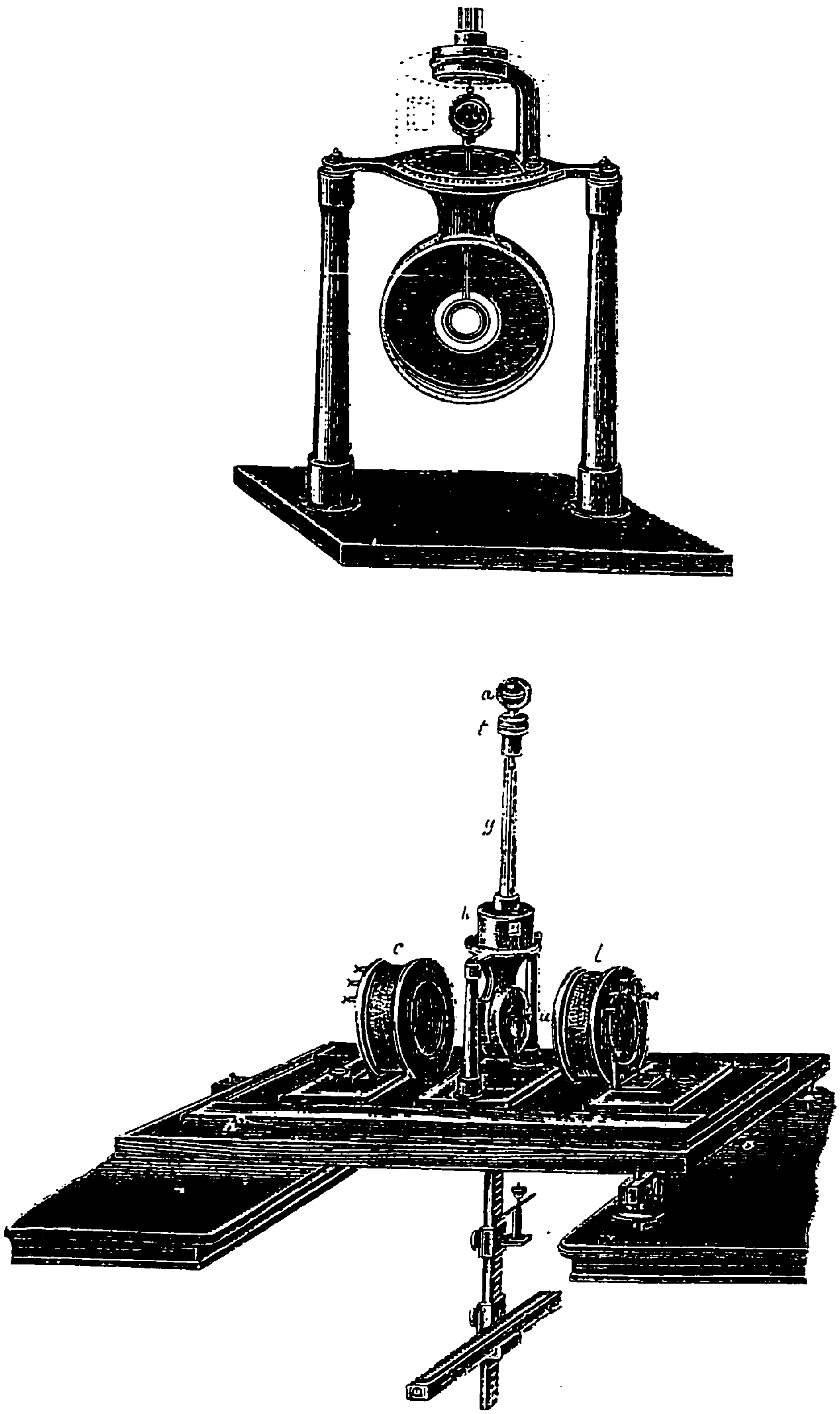

Figure 5. Gustav H. Wiedemann's mirror galvanometer. From I. v. Cyon, *Atlas zur Methodik der physiologischen Experimente und Vivisectionen* (1876) Plate XLV

turned up."[417] Sechenov also changed the research programs of his students at the laboratory: V. P. Mikhailov previously engaged in biochemical research (colorimetry of the blood and colloid state of the protein substances) started investigations of the respiratory center, and Vvedenskii who had mainly carried out biophysical investigations on the nerve and muscle excitation, turned to research on the innervation of respiration in a frog.[418]

In his "galvanic investigations" Sechenov chose a new object – it was a preparation of the isolated central nervous system connected with isolated sciatic nerves and a piece of spinal cord with small muscles. The preparation was put in a humid chamber. Thus, it was in fact an electrophysiological investigation of the central nervous system *in vitro*: peripheral nervous influences and humoral factors, as well as impulses from the brain were excluded. In this case, the central nervous system was excited by electrical stimulation of the nerves, while the muscles served as indicators of the spreading of the excitation from the brain into the spinal cord and then to the periphery. Vvedenskii reported later that the procedure demanded great care and skill. Biocurrents were led through non-polarisable electrodes into the mirror galvanometer (*Spiegelbussol von Wiedemann*) to which Sechenov imparted the maximum possible sensibility.[419] The refined method and improved instrumentation made it possible to detect the weak spontaneous oscillations of the brain potentials, which appear to be one of the first studies of spontaneous electrical phenomena in brain functioning. A. F. Samoilov who was the first among Russian electrophysiologists to bring a device of a new generation, a

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[417] Sechenov to Mechnikov, letter d. 2 Feb. 1880, in Shtraikh, ed, *Bor'ba za nauku*, p. 103
[418] "Protokoly zasedanii Soveta St. Peterburgskogo universiteta za 1878-1880 and 1880-1881" ["Proceedings of the Council of St. Petersburg University for 1879-1880 and 1880-1881"] in Koshtoyants et al, eds. *Nauchnoe nasledstvo*, pp. 122-3
[419] Vvedenskii, "Sechenov. Nekrolog," in K. M. Bykov, ed., *Sechenov, Pavlov, Vvedenskii*, p. 67

string galvanometer, to his laboratory, stated that Sechenov knew all the subtle nuances of electrophysiological technique and was a master and virtuoso in his experiments.[420]

During dissection of the medulla oblongata the galvanometer connected to its cross-section and longitudinal section, Sechenov detected a deflection of the needle of the galvanometer as in the case of the isolated muscle or nerve. As these oscillations occurred without apparent reason, Sechenov called them "spontaneous oscillations," or in a German text "spontanne Entladungen." Sechenov related these spontaneous discharges to the motor impulses that originated in the medulla oblongata. He also noticed that with intensification of excitation "spontaneous discharges weaken and reduce and turn into rest which lasts for some minutes." And vice - versa, after rest, spontaneous discharges appear again more intensely. The changes of activity and rest coincided in Sechenov's experiments with the state of excitation and inhibition accordingly. He referred to it as a distinct periodic rhythmic electrical phenomenon in an isolated medulla oblongata and spinal cord.[421]

A decade later, in the 1890s the question of spontaneous electrical activity in the brain came sharply into focus: simultaneously several scholars succeeded in recording the 'spontaneous' oscillations of the brain potentials. Among the researchers engaged in the polemics on the priority in the discovery of the electrical activity of the brain it was Adolf Beck, who referred in his work to Sechenov's articles in *Pflügers Archiv* as the first study of spontaneous electrical phenomena in brain functioning. Beck, professor of physiology at Warsaw University was the collaborator and friend of I. R. Tarkhanov,

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[420] A. F. Samoilov, *Izbrannye stat'i i rechi [Selected Articles and Speeches]*, Moscow-Leningrad, 1946, p. 43. On Samoilov's research in the field of electrophysiology, Grigoryan, *A. F. Samoilov*, pp. 82-107

[421] I. Setchenow, "Galvanische Erscheinungen an dem verlängerten Marke des Frosches," *Pflügers Arch. ges. Physiol.* (1882) 27: 524-66. Cited from Sechenov, *Selected Works*, p. 235

formerly Sechenov's and Cyon's student, and later professor of physiology at the Medico-Surgical Academy.[422] Sechenov's 'galvanic researches' of 1880s were representative of a new phase in the study of the basic nervous processes with the application of electrophysiological methods that had become more sophisticated and refined.

Sechenov's sudden shift back to the problems of neurophysiology during his continuous absorptiometric studies has attracted attention of Soviet neurophysiologists and historians of medicine. Iaroshevskii has stated that Sechenov's decision to interrupt his work on salt solutions was connected with a "constant argument between Sechenov and Vvedenskii" over the interpretation of the inhibitory phenomenon in the central nervous system.[423] The Soviet neurophysiologist Roitbak has argued that "the conflict of ideas" between Sechenov and Vvedenskii occurred much later. Vvedenskii's work of 1879 on the periodicity of breathing and innervation of movement and the respiration in a frog, did not contain any thesis, which could have led Sechenov to revise his theoretical ideas on the central nervous inhibition. However, Roitbak suggests that some of Vvedenskii's assumptions on the close connection between the respiratory and locomotor centers could have attracted Sechenov's attention, since Sechenov's earlier investigations on the central nervous system had shown that there was a similarity in the structure and features of both the respiratory and locomotor centers.[424]

[422] On the polemics over the priority in the discovery between several researchers - Ernst Fleishl von Marxow (1846-1892) from Vienna, Victor Horsley (1857-1916) and Francis Gotch (1853-19130 from England, and Adolph Beck (1863-1942) from Warsaw (anticipated by the work of Richard Caton in 1875), see Brazier, *A History of Neurophysiology in the Nineteenth Century*, pp. 193-6
[423] Iaroshevskii, *Sechenov*, p. 324
[424] Sechenov, *Fiziologiia nervnoi sistemy*, p. 58; see also Roitbak, "Vklad Sechenova v elektrofiziologiiu," in Kostiuk et al, eds, *Sechenov*, pp. 175-6

It seems plausible that in 1882 Sechenov again attempted to refute the objections to his theory of nervous inhibition. Vvedenskii never commented on the reasons of Sechenov's return to the problems of neurophysiology; he simply just pointed to the gap in thirteen years since Sechenov's last experimental research on the problem.[425] However, he had returned to the problem earlier, in 1872, when he had proved experimentally that the inhibitory process could occur outside of the central nervous system, in the peripheral nerves, but only under certain type of excitation (990 impulses a second).[426] In 1875 he published two papers, in which he refined his arguments based on the logical comparison of the experimental results obtained in 1868 and in 1872, the arguments which, as he understood, were still lacking direct evidence. The first paper was a critical review of Cyon's theory of interference inhibition, and the second was the answer to the critic of Ernst Brücke who, as Sechenov believed, was wrong in interpreting the mechanism of inhibition in central nervous system.[427]

In the *Galvanische Erscheinungen* Sechenov again presented a critical review of the existing theories of central nervous inhibition: the so-called 'theory of nervous fatigue' of Moritz Schiff and 'theory of interference' of Cyon, and related the new results to his vision on the nature of the inhibition in general and the central nervous inhibition in particular.[428] Sechenov saw the importance of his 'galvanic studies' primarily in the fact that they confirmed his concept of specific inhibitory centers in the mid-brain with a new experimental proof. In the conclusion of his *Galvanische*

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[425] Vvedenskii, "Sechenov. Nekrolog," in Bykov et al, eds. *Sechenov, Pavlov, Vvedenskii*, p. 66-7
[426] I. Setchenow, "Einige Bemerkungen über das Verhalten der Nerven gegen sehr schnell folgende Reize," *Pflügers Arch. ges. Physiol.* (1872) 5: 114-9
[427] I. Sechenov, "Zur Frage über Reflexhemmungen," *Bull. Acad. sci. St.- Petersb.*, ser. 3 (1875) 20: 537-542; I. Setchenow, "Notiz, die reflexhemmenden Mechanismen betreffend," *Pflügers Arch. Ges. Physiol.* (1875) 10: 163-169
[428] Sechenov, "Galvanische Erscheinungen," in Sechenov, *Selected Works*, p. 241

Erscheinungen he wrote: "Thus the major results of my first work on inhibition have sustained a new trial; the effects of the stimulation of the middle section of the brain correspond to inhibitory actions on its reflexes, and the same effects of the peripheral inhibition correspond to exito-inhibitory actions."[429]

In his galvanic experiments, as in his major work of that time on salt solution, the pattern remained the same: the problem arose from deeper understanding of his previous researches, and the instrument and method were refined and adapted to solve the problem, thus instantiating the connections between theory and experiment, a concept and practice. Analyzing Sechenov's attempt to confirm his concept, Vvedenskii noted, however, that Sechenov had changed his views on the specificity of central nervous inhibition and preferred to leave that question open for new investigations. Vvedenskii drew a parallel from the contemporary history of physiology: du Bois-Reymond's concept on the electrical phenomena in nerve and muscle, which with time underwent changes and began to be viewed from a different prospective. Vvedenskii worked in both laboratories, du Bois-Reymond and Sechenov's, and believed that both physiologists were path-breakers in the field.[430]

Now we will look more closely at Sechenov's major research project of 1876-1888 carried out at St. Petersburg University's laboratory, his absorptiometric studies of the blood and salt solution within the broader context of blood gas researches in Germany and the debate on theory of solution between Mendeleev and Ostwald's physico-chemical school.

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[429] *ibid*, p. 242
[430] Vvedenskii, "Sechenov. Nekrolog," in Bykov, ed., *Sechenov, Pavlov, Vvedenskii*, p. 68

3. A "Simple" Model: A Transition from Blood Gas Research to the Research on Salt Solutions.

The attempts of the leading German physiologists Ludwig, du Bois-Reymond and Helmholtz to follow the course of physical and chemical changes of isolated organs by means of measurements by appropriate instruments became the core element in Sechenov's approach to the problem of blood gases during his Odessa and St. Petersburg periods (1873-1888). His objective was to develop further a quantitative theory of the chemical processes underlying the respiratory function of the blood. Although Sechenov succeeded in modifying Meyer's apparatus and assimilating to it aspects of some other lines of inquiry in respiratory physiology, the absorption characteristics of the blood gases in particular, the objective was not achieved until the beginning of the twentieth century when British physiologists John Scott Haldane (1860-1936) and Sir Joseph Barcroft (1872-1947) developed improved and simplified analytical techniques for the determination of blood gases.[431]

The state of a gas absorbed by liquids, as Sechenov indicated, was studied generally in two ways: first, by observation of various conditions of its isolation from the liquid, and secondly, by investigation of the conditions of its absorption by liquids. Starting with investigations on the state of CO_2 in the liquid part of the blood as well as in the red blood corpuscles, Sechenov proceeded by the second way, which in his opinion was 'undoubtedly more fruitful.'[432]

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[431] John S. Haldane, professor of physiology in Oxford, suggested in 1900 a very fast and accurate method using ferricyanide for determining the oxygen content in 20 ml blood samples with high precision, to 0.2 per cent accuracy. Together with Joseph Barcroft, professor of physiology in Cambridge, Haldane described in 1901 a new modification of the ferricyanide method for determining oxygen and carbon dioxide in the same sample. See Astrup, *The History of Blood Gases, Acids and Bases*, pp. 146, 161
[432] Sechenov, *Autobiographical Notes*, p. 138

In his work of 1859 Sechenov had referred to the research methods of Emile Fernet on serum and Lothar Meyer on whole blood. In both sets of experiments, the quantity of carbon dioxide, which occurred in the blood in a state of chemical binding (e. g. carbon dioxide which remained in the blood when blood was placed in the vacuum) 4-6 times exceeded the quantity of 'free', e. g. extracted carbon dioxide. Using the apparatus of his modification Sechenov managed to show that nearly all carbon dioxide, contained in the blood, was in the 'free' state, therefore it could be liberated to the vacuum. Though both of these methods, of Fernet and of Meyer, gave valuable individual results, the basic question on the state of carbon dioxide in the blood still remained unclear. Sechenov pointed to Meyer's experiments of 1857, which had shown that carbon dioxide dissolved in the blood did not follow the Dalton-Henry law, so it became evident that carbon dioxide was not in a state of physical binding but rather in a state of loose or reversible chemical binding.[433]

At that stage of his investigations the crucial question for Sechenov as well as for other researchers who attempted to study the CO_2 content in the blood became not to obtain as accurate test results as possible but, rather, to determine whether carbon dioxide in the blood occurred in a bound state or in a free state: "It is evident that the important question of freeing the body from CO_2 by respiration is directly connected with the question on the state of CO_2 in the blood."[434]

Sechenov was well aware of the blood gas research in Ludwig's laboratory in Leipzig, which confirmed the presence of carbon dioxide in the blood cells, but did not clarify the problem of its state in the blood; Meyer in 1857 and later Alexander

[433] Setschenow, "Beiträge zur Pneumatologie des Blutes," in Sechenov, *Selected Works*, p. 3
[434] *ibid*, p. 4

Schaffer[435] from Ludwig's laboratory in Vienna claimed that most of the blood CO_2 was carried in the plasma. Sechenov started the experiments with the blood serum to analyze its alkalinity and to find out, how far and for how long the absorptiometric properties of the serum remained constant. He established a significant dependence of the chemical absorption upon pressure in the serum, and seeking an explanation of that fact, he performed in greater detail the experiments of Emile Fernet, and Lothar Meyer and Rudolf Heidenhain with solutions of sodium carbonate ($Na_2 CO_3$) and of sodium hydrogen phosphate ($Na_2 HPO_4$). But his results still could not explain the phenomenon. Sechenov reasoned that although Na_2CO_3 (a salt produced by weak carbonic acid, as a result of dissociation of CO_2 in water) played an important role in the absorption of CO_2 by the serum, its absorption in the blood was different from a pure water solution. However, uptake by inorganic salts and water could be regarded as a simplified model system for the uptake of carbon dioxide by blood. Sechenov started a new series of experiments on the absorption of CO_2 by solutions of other salts formed by weak acids, which are capable of binding CO_2 chemically. From that time on Sechenov's research work broke into two parts - with blood, and with salt solutions. The experiments grew in number and complexity, and the results, obtained with salt solutions were interesting in terms of their novelty, and could also elucidate the phenomena presented in the blood.

These experiments resulted in the assertion that "the magnitude of chemical absorption of CO_2 in the serum in regard to its respiratory function is better than water, and better than an aqueous solution of alkali carbonate. It [serum] draws CO_2 from the tissues more strongly than water and gives it up in the lung cavity more easily than

[435] A. Schäffer, "Über die Kohlensäure des Blutes und ihre Ausscheidung mittels der Lunge," *Sitzungsb. k. Acad. Wissensch.* (1860) 41: 589-94

bicarbonate." Sechenov attributed that ability of the serum to the presence of globulins in it: if the globulins were precipitated by the addition of magnesium sulphate, $MgSO_4$, the liquid remaining showed only faint signs of weak chemical absorption of CO_2.[436]

The experiments with the blood went in their own sequence. Investigating the absorption of carbon dioxide by erythrocytes, Sechenov demonstrated that carbon dioxide was present in the erythrocytes not only in the state of physical solution and in the state of bicarbonate, but in a state of weak chemical bonding with haemoglobin. He succeeded in isolating haemoglobin by inducing it to crystallize by repeated freezing and settling of horse blood samples. Now he could compare the absorptiometric characteristics of a suspension of corpuscles, of the liquid remaining after the precipitation of the hemoglobin, and of haemoglobin itself. The experiments demonstrated that haemoglobin was able to bind CO_2 dissociably.

These were important results. As early as 1857 Lothar Meyer demonstrated chemical binding of oxygen in the blood. Independently of Claude Bernard, he also found that carbon monoxide was capable of quantitatively expelling oxygen from the blood.[437] Felix Hoppe-Seyler, while investigating the *Blutfarbstoff*, isolated it as a crystalline substance and called it haemoglobin. Applying analytical methods from physics and chemistry: colorimetry, polarization and spectrum analysis, he identified it by means of its absorption spectrum and decomposed it into bile pigments.[438] Later Hoppe-Seyler demonstrated that haemoglobin within red corpuscles carried oxygen in a loose chemical bond, which could be blocked by exposing the blood to carbon monoxide

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[436] Sechenov, "Beiträge zur Pneumatologie des Blutes," in Sechenov, *Selected Works*, pp. 11-2
[437] Meyer, *Die Gase des Blutes*, p. 85
[438] F. Hoppe-Seyler, "Über das Verhalten des Blutfarbstoffes im Spectrum des Sonnenlichtes," *Virchows Archiv für path. Anat. u. Physiol. u. für klin. Med.* (1862) 23: 446-9

gas. The method of spectroscopy enabled Hoppe-Seyler to show a weakly bound chemical compound, which he called oxyhaemoglobin, that would explain the chemical bonding of oxygen in blood. Since the main mass of O_2 can unite with haemoglobin, erythrocytes were considered the transmitters of O_2 from the external atmosphere into the tissues.[439]

Based on his experimental data, Sechenov assumed that erythrocytes, due to their high absorption capacity for CO_2, could also be considered as the transmitters of carbon dioxide from the tissues to the external environment. The results of that research were published in 1874.[440] The problem of carboxyhaemoglobin and its role in the processes of gas exchange was later thoroughly investigated in the doctoral thesis of Christian Bohr (1855-1911), Ludwig's student in Leipzig. Bohr made use of Sechenov's absorptiometric technique to find that each gram of haemoglobin would bind approximately 2.4 ml CO_2 at a pCO_2 of 30 mmHg. Bohr's later researches during his professorship at the University of Copenhagen were concentrated on the elaboration of refined techniques of physical measurement of processes underlying the physiological functions.[441]

One of the most interesting points in Sechenov's treatment of the problem of blood gases is his expressed attempt to construct a simple model in which a water

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[439] F. Hoppe-Seyler, *Handbuch der physiologisch- und pathologisch-chemischen Analyse für Ärzte und studierende,* 2 ed, Berlin, 1865, pp. 203-5, 207-8

[440] I. Setschenow, "Über die Absorptionmetrie in ihrer Anwendung auf die Zustande der Kohlensäure im Blute," *Pflügers Arch. ges. Physiol.* (1874) 8: 1-39

[441] Ch. Bohr, *Experimentalle Untersuchungen über die Sauerstoffaufnahme des Blutfarbstoffes,* Copenhagen, 1885. The elucidation of the various forms of carbon dioxide binding in the blood proved to be a much more difficult undertaking than unraveling of the problems surrounding the binding of oxygen. It was not until 1914 that J. S. Haldane was able to establish conclusively that carbon dioxide was more strongly bound to non-oxygenated blood than to oxygenated blood, the so called "Haldane effect," see Astrup, *The History of Blood Gases,* p. 160. On the influence of Christian Bohr on his son Niels (1885-1962), future professor of physics, famous for his atomic and nuclear researches, see L. Rosenfeld, "Niels Bohr," in *Dict. of Scient. Biog.*, v. 2, pp. 239-54.

solution represented blood:

> If we imagine for a moment that water instead of blood flowed through our veins, that with the capability of the latter of dissolving carbonic acid and giving it up by means of diffusion to the atmospheric air it could apparently take the place of blood very well. If one imagines further, blood replaced by a weak solution of sodium carbonate not fully saturated with carbonic acid to the formation of a bicarbonate, then this liquid also could apparently function successfully - to draw CO_2 from the tissues to saturation and give up surplus in the lungs, since a bicarbonate solution exposed to air loses CO_2.[442]

As Timothy Lenoir points out, an analog model is not intended to be a true description of the prototype: it need not reproduce all the characteristics of the prototype but only certain salient features considered relevant.[443] Sechenov's attempt to model the absorption of gases by blood in terms of the analogy to the absorption of gases by salt solutions, employed in physical chemistry, enabled him to refine the absorptiometric technique and to establish more exact quantitative parameters of the phenomena under investigation. Sechenov reasoned that a simple model, which established an analogy to the other, better understood area, particularly to the conception of the solution of gases in liquids. In that case, the model could function as an interpretive schema for applying a chemical theory to the problem of various forms of carbon dioxide binding in the blood.

What Sechenov did not realize at that point was the complexity of his seemingly simple model. Later, recollecting his experimental work at Novorossiisk University, Sechenov wrote: "For almost five years here, I studied the problem of the state of carbon dioxide in the blood. This, apparently, quite simple question required for its solution not only experiments with all principal elements of the blood separately and in various

[442] Sechenov, *Autobiographical Notes*, p. 138
[443] Lenoir, "Models and Instruments," in *Hisorical Studies in the Physical and Biological Sciences.*, p. 3

combinations with each other, but moreover - with a long series of salt solutions."[444]

Sechenov could not possibly foresee all difficulties and uncertainties with which he had to deal studying the problem of salt solution. As the historian of chemistry R. Dolby remarked, until the last third of the nineteenth century, relatively few chemists dealt with the nature of the solutions as a problem in its own right and as a problem around which questions about the phenomena of solution could be organized.[445] Sechenov, a trained physiologist with physico-chemical background, entering the field of chemistry of solutions, inevitably became captivated by challenge of "finding the key to a vast class of phenomena not yet known to anyone."[446] That was a turning point in his research: from a simple model to a full scale investigation aimed to establish a general dependence between the quantity of gases absorbed by salt solutions and concentration of salts in these solutions.

Sechenov, "whom the fate suddenly threw into a foreign field,"[447] sought advice and instruction regarding his research with solutions from Mendeleev, by then the most powerful and respected chemist in the country. Mendeleev's conception of solutions and the controversy over hydration between him, Arrhenius and Ostwald creates a context for Sechenov's work on the absorption of gases by salt solutions. To put these matters into proper perspective, it is necessary first of all to present a brief history of the theory of solutions with a particular stress on Mendeleev's contribution.

A debate over the theory of solutions in the second half of the nineteenth century

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[444] Sechenov, *Autobiographical Notes*, p. 138

[445] R. G. Dolby, "Debates over the Theory of Solution: A Study of Dissent in Physical Chemistry in the English -Speaking World in the Late Nineteenth and Early Twentieth Centuries," *Historical Studies in the Physical Sciences* (1976) 7: 297-404 (300)

[446] Sechenov, *Autobiographical Notes*, p. 156

[447] Sechenov to Mendeleev, letter d. Odessa, 17 October 1873, cited in Koshtoyants, ed, *Nauchnoe nasledstvo*, p. 218

is in itself an important episode in the history of science.[448] A review of that helps to see how physiological studies of blood gases were related to the chemistry of solutions. It also gives valuable insights into Sechenov's attempt to incorporate practical and theoretical advances in the field of chemistry of solutions into his research on the absorption of gases by the blood and salt solutions.

Apparently, Sechenov was well aware that Mendeleev had been developing his hydrate theory to explain the properties of solutions. Mendeleev noted later: "I was deeply interested in the problem of indefinite chemical combinations, especially of solutions and alloys, and their close connection with definite combinations right from the beginning of my scientific career (in the 1850s and 1860s)."[449] For Mendeleev, the investigation of solutions, particularly aqueous solutions, was "especially interesting as in the earth and in the water, in plants and in animals, in chemical enterprises and industry there appear solutions, and they play an important role in chemical transformations."[450]

Mendeleev's first articulated assertion of the theory of solutions appeared at the time when a new question about the nature of the solution came sharply into focus as

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[448] The initial period in the development of theories of solutions is thoroughly presented in P. I. Val'den, *Teorii rastvorov v ikh istoricheskoi posledovatel'nosti [Theories of Solutions in their Historical Sequence]*, Petersburg, 1921. For a German version, see P. Walden, "Die Lösungstheorien in ihrer geschichtlichen Aufeinanderfolge," in *Sammlung chemischer und chemisch-technischer Vorträge* (1910) 15: 277-454. Paul Walden (1863-1957), chemist and historian of science, worked in Riga (then a Russian town) from 1882-1919, then in Rostock and, finally, in Tübingen. Walden was a close friend of Ostwald and his co-worker. Their correspondence, that lasted for more than forty years, is published in *Wilhelm Oswald und Paul Walden in ihren Briefen*, R. Zott, ed., with introduction by R. Zott, "Paul Walden – Wissenschaftler zwischen den Kulturen?" pp. 12-63. My interpretation of the hydrate theory has been greatly guided by Iu. I. Solov'ev's, *Istoriia ucheniia o rastvorakh [History of Theory of Solutions]*, Moscow, 1959, a thorough account of the theories of solution from the end of the eighteenth century till the 1930s. Solov'ev has provided a comprehensive discussion on the development of Mendeleev's hydrate theory and the controversy over hydration between Mendeleev and Arrhenius, as well as a historical survey of the debate on theories of solution in Russia and Germany.

[449] D. I. Mendeleev, *Osnovy khimii [Principles of Chemistry]*, 9 ed, 2 vols, Moscow-Leningrad, 1927, p. 235, cited in Solov'ev, *Istoriia ucheniia o rastvorakh*, p. 54

[450] Mendeleev, *Osnovy khimii*, pp. 26-7, cited in *ibid*, p. 53

physical and chemical forces became more strongly contrasted. In his doctoral dissertation *On the Combination of Alcohol and Water* (1865), Mendeleev developed an idea that solutions are not mechanical mixtures but chemical combinations, moreover they were "ordinary examples of chemical reactions," interactions between solvent and soluble that are not to be distinguished from other forms of chemical compounds. Dealing with the problem of the connection of definite and indefinite combinations in solution, Mendeleev sought to clarify the question whether solutions, particularly water solutions, were to be understood as containing definite chemical species produced by the dissolved substance and the water.[451]

It was most plausible for Mendeleev to explain the chemical nature of the connection between solvent and soluble by the formation in the solution of definite combinations (such as hydrates). He pointed out, that in many cases the dissolution was accompanied by the phenomena associated particularly with chemical compounds, for example the liberation of heat and a sharp change in the properties of the solutions. There also existed hard crystalline solutions, and combinations with water of crystallization.[452]

Mendeleev tried to link the notions of chemistry of definite proportions, which became prominent in the wake of Dalton's atomistic theory, to Claude Berthollet's conception of indefinite proportions.[453] That, as Mendeleev believed, would enable him to draw distinction between compounds and solutions:

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[451] D. I. Mendeleev, *Rastvory*, Moscow, 1957, pp. 381-82; on Mendeleev's doctoral dissertation, and early development of his theory of solutions, see N. A. Figurovskii, *D. I. Mendeleev*, Moscow, 1961, pp. 170-87, see also Solov'ev, *Istoriia ucheniia o rastvorakh*, pp. 57-9
[452] Solov'ev, *Istoriia ucheniia o rastvorakh*, pp. 59-60
[453] Claude Louis Berthollet (1748-1822), a French chemist, accompanied Napoleon's expedition to Egypt in 1798, where he made some mineralogical analysis that enabled him to conclude that mass action (concentration) could overcome the usual play of elective affinities between substances. Later he proposed

In my mind solutions are not alien to the atomistic notions. Along with common definite combinations, solutions are included in the circle of those notions which prevail now in the studies of the mass action law,[454] of dissociation and of gases, and at the same time, solution for me is the most common case of a chemical action (force) which is determined by a relatively weak affinity, and therefore is a fruitful field for further development.[455]

By the 1870's the refinement of techniques and the expansion of chemists' experimental activities, particularly the thermochemical studies of Julius Thomsen in Copenhagen and Marcellin Berthelot in Paris,[456] provided an important source of data on the state of substances in solution and on the problem of simultaneous action of several solvents. Marcellin Berthelot attributed the heat, liberated when a substance is dissolved, to chemical combination of the dissolved substance with the water. He presented an influential full statement of the hydrate theory in his 1879 paper where he stated that solution of salts occurs with the formation in the solution of definite compounds between the salt and the water, analogous to or identical with the hydrates of constant

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that compounds combined together in variable and indefinite proportions, and he pointed to solutions and alloys, and what would today be defined as mixtures, as empirical evidence for his claim. Thus he did not make a sharp distinction between compounds and solutions and regarded solutions as compounds in indefinite proportions. See Brock, *The Norton History of Chemistry*, pp. 144-5; and J. W. Servos, *Physical Chemistry from Ostwald to Pauling: The Making of a Science in America*, Princeton, 1990, pp. 13-6; see also M. P. Crossland, *The Society of Arcueil: A View of French Science at the Time of the Napoleon I*, Cambridge, Mass., 1967, pp. 57-60

[454] The mass action law made it possible to express the working of chemical forces by means of mathematical formula. It was drawn up by the Norwegian brothers-in-law Cato Guldberg (1833-1902) and Peter Waage (1833-1900) both professors (the former a mathematician, the latter a chemist) at the University of Christiania (Oslo) in 1867. The law had been virtually unknown until Wilhelm Ostwald (1853-1932) in his doctoral thesis (1877) on the problem of chemical affinity referred to it and through that reference van't Hoff (1852-1911) was enabled to reinterpret the Norwegians' work thermodynamically. See Brock, *The Norton History of Chemistry*, p. 379

[455] Mendeleev, *Rastvory*, in idem, *Izbrannye sochineniia*, 4 vols, Moscow, 1937, cited in Soloviev, *Istoriia ucheniia o rastvorakh*, p. 62

[456] The extensive calorimetric researches pursued by Marcellin Berthelot (1827-1907) in France and Julius Thomsen (1826-1908) in Denmark were stimulated by the earlier investigations on the heats of the reactions which stated that the amount of heat liberated in the neutralization of acids by bases was always the same, no matter how many reaction pathways were used. This 'law' was to be found in the later dissociation theory. See Brock, *The Norton History of Chemistry*, pp. 360-1

composition known in the crystalline state.[457]

The basic principles of his conception of solutions, his ideas on the formation of definite combinations, i.e. associations of hydrated molecules in a state of uneven dissociation and dynamic equilibrium, which are governed by the mass action law, were developed by Mendeleev by 1886. Outside Russia, Mendeleev's conception of solution attracted attention after publication of a paper in 1886,[458] in which he demonstrated the existence of hydrates by using data on the general properties of solutions. Mendeleev's method consisted of plotting the differential of the relative density of the solution (*s*) against the percentage composition (*p*). It resulted in a graph with straight lines, each of which was taken to represent a specific hydrate. When the lines were broken due to increasing dilution, Mendeleev took these points of discontinuity [*Knickes* or breaks] to mean that a complex hydrate had disappeared, leaving a single hydrate containing a lower proportion of water. Mendeleev claimed that the method could be extended to prove the existence of hydrates using other properties of solution, among them electrolytic conductivity.

Mendeleev's extensive experimental data supported his generalizations and hypotheses on the dependence of specific weights on composition. They were systematized in a well-built theory and presented in his monograph published in 1887 in St. Petersburg.[459] Later Mendeleev wrote regarding that work: "Partly from this, there appeared a kind of vogue for solutions. My ideas on solutions from my youth till now

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[457] M. Berthelot, *Essai de méchanique chemique fondée sur la thermochemie,* Paris, 1879, 2, 162, see Dolby, "Debate over the Theory of Solution," p. 302

[458] D. Mendeleev, "Über die nach der Veränderungen des spezifischen Gewichtes beurtheilte chemischen Assoziation Schwefelsäure mit Wasser," *Ber. dt. chem.Ges.* (1886) 19: 379-389

[459] D. I. Mendeleev, *Issledovaniia vodnykh rastvorov po udel'nomu vesu [Studies on Aqueous Solutions Based on their Specific Weights]*, St. Petersburg, 1887

are the same: there is no distinction between the solution and chemical phenomena. I am glad that I have had time to state my ideas. And I am glad to dedicate this work to my mother to whom I own everything."[460] Indeed, in his early works of 1859-1862 Mendeleev made known his agreement with the unitary and type theories of Gerhardt (to which he adhered throughout his life), and his opposition to Berzelius's electrolytic theory of the formation of chemical compounds. In his later works, he declared his opposition in general to linking chemistry with electricity and preferred associating it with physics as a science of mass. Mendeleev's predilection found its most brilliant vindication in the correlation he achieved between the chemical properties and atomic weights of the elements.[461]

Among the chemists who had intermittently turned their attention to the general field of solution theory along with Mendeleev were Henry Armstrong (1848-1937) in London and François Raoult (1830-1901) in Grenoble. Although they attacked the problem of solution theory from very different angles, they were in agreement in giving precedence to chemical reactions between the solute and the solvent. Since the solvent was most often water, they thought that solutions, including electrolytic solutions

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[460] D. I. Mendeleev, *Literaturnoe nasledstvo [Litarary Heritage]*, 2 vols, Leningrad, 1938, v. !, p. 80 Mendeleev's mother Maria Kornileva, at the age of 57 with her youngest son, her fourteenth child, Dmitrii hitch-hiked 14000 miles from Siberia to Moscow and then to St. Petersburg in 1850 to place her son to the Main Pedagogical Institute, and in order to devote him to science spent her last resources and strength.
[461] Charles Gerhardt (1816-56) rejected Berzelius's dualistic view of molecules for a unitary one, which eventually allowed chemical properties to be ascribed to the arrangements of atoms. Through the influence of his *Traité de chemie* (1848) came the idea of types, the revision of atomic weights, the idea of valency and the structural theory of organic molecules. In his letter (Heidelberg, 1860) to his teacher A. A. Voskresenskii, professor of chemistry at St. Petersburg University Mendeleev presented a full account on the Congress in Karlsruhe (1860) and his views on the important issues discussed at the Congress, particularly Gerhardt's type theory. See Mladentsev and Tishchenko, *Mendeleev*, pp. 250-258. On Mendeleev's early studies of the chemical properties of substances, his work on the specific weights and their relationship to atomic and molecular weights, see V. M. Kedrov and D. N. Trifonov, *Zakon periodichnosti i khimicheskie elementy. Otkrytiia i khronologiia [The Law of Periodicity and the Chemical Elements. Discoveries and Chronology]*, Moscow, 1969, pp. 127-40. Literature on Mendeleev in Russian is immense. On the role of Mendeleev in Russian science and culture, see A. Vucinich, "Mendeleev's Views on Science and Society," *Isis* (1967) 58: 342-351

involved the formation of the hydrates (a crystal formed through the combination of a compound with water). In addition the hydrationists, as they became known, attributed special importance to the role of molecular aggregates, that is for them salts in solution existed in the form of complex molecules or molecular complexes.[462]

With the appearance of the work of van't Hoff on dilute solutions[463] and Arrhenius's theory of electrolytic dissociation,[464] an alternative view of solution became possible. The solution began to be seen in terms of a physical, rather than a chemical theory. At the Physico-Chemical Institute of Leipzig University Wilhelm Ostwald (1853-1932) originated a new and prolific school of research, which was mainly based on Arrhenius's theory of electrolytic dissociation, van't Hoff's osmotic theory of solutions, and applications to chemistry of the laws of thermodynamics. The Ionists, so named because they believed that chemical reactions in solutions involve only ions and not undissociated molecules, were aware that the idea of dissociation required chemists

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[462] On Raoult's important work on freezing points of solutions see, Partington, *A History of Chemistry*, v. 4, pp. 645-648; on Armstrong and the British discussion of electrolysis and solution see, Dolby, "Debates over the Theory of Solution," pp. 309-21; on Armstrong studies with Kolbe in Leipzig in 1867-70 see, Rocke, *The Quiet Revolution*, pp. 284-85.

[463] Jacobus H. van't Hoff (1852-1911), from 1878 professor of Chemistry in Amsterdam, and from 1896 at the University of Berlin. Van't Hoff's studies of osmotic pressure suggested that the analogy between gases and solutions was complete. He found (1885) that at equal osmotic pressure and temperature, equal volumes of solutions contain an equal number of molecules, ... the same number which, at the same temperature and pressure, is contained in an equal volume of gas. In the paper "Die Rolle des osmotisches Druckes in der Analogie zwischen Lösungen und Gasen" published in the first volume of the new *Zeitschrift für Physikalische Chemie* (1887, S. 483-508) van't Hoff at the suggestion of Arrhenius reinterpreted his work in terms of ionization. The first Nobel Prize in Chemistry was awarded to van't Hoff in 1901. See Brock, pp. 370-371; on the range of physical chemistry and its history, see K. J. Laidler, *The World of Physical Chemistry*, Oxford, 1993, pp. 207-19

[464] Svante Arrhenius (1859-1927), professor of physics at the University of Stockholm in the 1890s and later director of the Nobel Institute of for Physical Chemistry, presented his theory of ionic dissociation in the paper "Über die Dissoziation der in Wasser gelösten Stoffe," *Z. phys. Chem.* (1887) 1: 631-648, in which he suggested that the dissociation of certain substances dissolved in water was strongly supported by the conclusions drawn from the electrical properties of the same substance. The Noble Prize in Chemistry - 1903. Later Arrhenius became interested in immunochemistry, postulating a chemical equilibrium between toxin and antitoxin. The most recent biography of Arrhenius is E. Crowford, *Arrhenius: From Ionic Theory to the Greenhouse Effect*, Canton, MA, 1996; see also Iu. I. Solov'ev, *Svante Arrenius. Nauchnaia biografiia [Scientific Biography]*, Moscow, 1990

to change the prevailing conceptions of the chemical nature of salts and related substances and to step forward from molecular chemistry to chemistry of ions. The fundamental notion of the indivisibility of the atom was incompatible with the notion of ions as specific state of matter. Ostwald recalled in his autobiography, *Lebenslinien*, that during his visit to the laboratory at the University of Uppsala he had a conversation with professor of chemistry Per Theodor Cleve (1840-1905) about Arrhenius's ideas on electrolytic dissociation (Ostwald acknowledged that the theory had not yet been clearly formulated): "With iron logic, Cleve made conclusions one after another from Arrhenius's major hypothesis, and at last asked me: "So, you believe that here in a glass with a solution of sodium chloride [table salt in water] atoms of sodium are floating separately?" And when I answered positively, he glanced at me as if doubting in my chemical common sense."[465]

The dissociation theory was the main target of the attack on Ostwald's school by Mendeleev and the British hydrationists, who had embraced Mendeleev's method as stated in his work on aqueous solutions based on their specific weights (1886). The Ionists were thus confronted not only with the hydrate theory as an alternative but also with a method to show that it was correct.[466] Even though Arrhenius and Ostwald by 1889 had a great variety of experimental data to support the idea of dissociation there were still important issues that could not be explained in terms of dissociation, particularly the source of energy necessary for the dissociation.

[465] W. Ostwald, *Lebenslinien: eine Selbstbiographie*, 3 vols in 1, v. 1, p. 223. In the 1880's it seemed incredible to many chemists that in aqueous solution of sodium chloride atoms of sodium (a soft silver-white alkali metal violently reacting with water) and atoms of chlorine (a yellow-greenish suffocant gas) were in a free state. Cleve, one of the notable Swedish chemists, investigated very fully some of the rare-earth elements. He strongly opposed Arrhenius's appointment as docent in physical chemistry at the University of Uppsala. On Cleve and Arrhenius, see Crawford, *Arrhenius*, pp. 59-60

[466] On the reaction of the British chemists to the Ostwald School Theory see, Dolby, "Debate over the Theory of Solution," pp. 323-327; see also Crawford, *Arrhenius*, p. 99

Mendeleev started a debate by publishing in the *Journal of the Russian Physico-Chemical Society* an article where he sharply rejected "a specific type of dissociation, into ions, in the electrolytes during formation of weak solutions." In Mendeleev's view in the process of solution *association* prevailed, that is, formation of the new complex but with weak and easily dissociated combinations.[467] Arrhenius at once published his answer to Mendeleev in the *Philosophical Magazine*. He started his article with a critical remark regarding the contradictory manner in which "the distinguished Russian chemists" presented theory of electrolytic dissociation in the Russian journal. Arrhenius criticized Mendeleev for ignoring a great part of what had been accomplished by the theory of dissociation. He stated that the theories of dissociation and osmotic pressure in the application to solutions made it possible for the first time to calculate the numerical values of thousands of observations with no contradiction between the theory and experiment. He further argued that the hydrate theory was useless as so far, not a single numerical datum had been deduced from this hypothesis. Dissociation theory, Arrhenius claimed, was antagonistic to the statement that hydrates existed in dilute solutions with a large quantity of water as asserted by Mendeleev.[468]

Arrhenius's arguments did not convince Mendeleev. Mendeleev could not accept the very idea of dissociation and the concept of the ion as an electrically charged molecular fragment. In his view the history of development of chemistry had confirmed the unitary theory, which disclaimed "preexistence of opposite constituents." Elsewhere Mendeleev stated that Arrhenius's theory "violates common and conventional principles

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[467] D. I. Mendeleev, "Zametki o dissotsiatsii rastvorennykh veshchestv" ["Notes on Dissociation of Substances in Solutions"] in *Zhurnal Russkogo fiziko-khimicheskogo obshchestva [Journal of the Russian Physico-Chemical Society]* (1889) 21(2): 175-6

[468] S. Arrhenius, "Electrolytic dissociation versus hydration," *Phil. Mag.* Ser. 5 (1889) 28: 30-1

of chemistry."[469] Mendeleev's critical stance towards the dissociation theory was strengthened by Ostwald's contradictory views on the atomic theory.[470] And finally, Arrhenius's concept of dissociation undermined a theory of solutions that Mendeleev had been developing for many years.

In turn the hydrate theory was strongly opposed by the German physico-chemical school. Walter Nernst, one of Ostwald's most enthusiastic disciples argued that hydrate theory could not be even called 'theory of solutions' as it had no theoretical foundation whatsoever and it did not result in the determination of any regularities.[471] In his publications Ostwald hardly ever mentioned hydrate theory. In his reviews of the works of the hydrationists published in his *Zeitschrift für physikalische Chemie*, he was skeptical both of their results and of their theoretical conclusions. Discussing the report of P. S. Pickering at the Leeds meeting of the British association in 1890 Ostwald remarked: "Even if the view that hydrates could exist in solutions is widely accepted, nevertheless, the method by which they have been found is rather peculiar, and not satisfactory."[472] Later in his autobiography Ostwald discussing briefly *die Lehre von den*

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[469] On the acceptance of Arrhenius's theory in Russia, see Iu. I. Solov'ev, *Svante Arrenius*, pp. 139-45

[470] Ostwald strongly opposed the atomic theory of matter until 1909. As Brock remarks, one of the ironies of the history of chemistry is that the ionic theory was to find its ultimate justification in the atomic theory of matter. See Brock, *The Norton History of Chemistry*, p. 379

[471] H. W. Nernst in his *Theoretische Chemie vom Standpunkte der Avogadroschen Regel und der Thermodynamik*, Stuttgart, 1893, gave a short characteristic of the hydrate theory and disputed the correctness of experimental as well theoretical foundation of Mendeleev's work of 1887, and expressed a strong doubt in the existence of the hydrates in the solutions. See, V. Nernst, transl., *Teoreticheskaia khimiia*, St. Petersburg, 1904, pp. 100, 432. Hermann Walter Nernst (1864-1941), Professor of Physics and then of Physical Chemistry at the University of Göttingen (from 1890) was a supporter of the ionic theory and with Ostwald described an experiment to demonstrate the existence of free ions by their motion in an electrostatic field (1889). Nernst is considered one of the more successful descendants of the original "triumvirate" of Ostwald, van't Hoff, and Arrhenius. Noble prize in 1920. See an excellent and the most recent biography of Nernst: D. K. Barkan, *Walter Nernst and the Transition to Modern Physical Chemistry*, Cambridge, UK, 1999

[472] See Ostwald's review of P. S. U. Pickering's report in Leeds, in *Z. Phys. Chem.* (1891) 7: 416-421, cited in Solov'ev, *Istoriia ucheniia o rastvorakh*, p. 333. On British discussion of electrolysis and solution 1880-1887, see Dolby, "Debates over the Theory of Solution," pp. 309-20

Knicken – [theory of the breaks], wrote that a debate on the problem of the nature of the solutions "...was stimulated by the interference of the well-known Russian chemist Mendeleev. ...Like many chemists of the time, he supposed that between the solvent and dissolved substance there occurred a chemical binding, and to prove that he used a method which was as original as it was wrong."[473] Nevertheless, in his letter to Mendeleev in 1888 Ostwald admitted the general scientific importance of Mendeleev's *Investigation of the Solutions Based on their Specific Weights*, even though its results were doubtful and not significant for him: "Your book contains an immense effort. I hope that elaboration of this problem will be extremely fruitful for science."[474]

Mendeleev' s high and influential standing created an intellectual climate for the hydration theory to prevail among Russian scientists. In Arrhenius's letter to van't Hoff in 1890 there is a fascinating passage on the possible reception of the new physico-chemical views in Russia: "... The Russians are in general very sympathetic towards the new direction, it corresponds so much to the Russian imagination. Only the great Mendeleev strongly holds back and the majority dare not reply to the great master and patriot. ...These are in a state of hypnotism in which they have to obey the hypnotism without resistance. And the analogy between gases and solutions ... lies deep in their sensibility."[475]

In his *Solutions*, published in England in 1891, Ostwald gives a good picture of the way solution theory looked from inside in 1891. In the "Preface" Ostwald stressed that the theory of solutions, founded by van't Hoff, had made in recent years remarkable

[473] Ostwald, *Lebenslinien*, v. 2, pp. 126-27
[474] D. I. Mendeleev, *Issledovaniia vodnykh rastvorov po udel'nomu vesu*, St. Petersburg, 1887. Ostwald to Mendeleev, letter d. Leipzig, 19 January 1888, cited in Solov'ev, *Istoriia ucheniia o rastvorakh*, p. 331
[475] Arrhenius to van't Hoff, letter d. Stockholm, 1890, cited in Barkan, *Walter Nernst*, p. 62

advances, both theoretical and practical. These became the reason why doubts had been cast on the solidity of the theory: "for the more rapid is the advance of new ideas, the more difficult is it for those who stand on one side to criticize these ideas."[476] Ostwald's detailed discussion on the developments in the solution theory and its present problems omits one important detail, without which the picture is not complete: he does not refer to the works on solutions by Mendeleev or by his British supporters P. S. U. Pickering and H. E. Armstrong. He says nothing whatsoever about the hydrate theory.[477] What Ostwald considers important enough to relate in detail in his *Solutions* was the result of Sechenov's experimental work on the absorption of gases by salt solutions. Notably, Ostwald discusses Sechenov's work alongside the research of several distinguished chemists of the time who were engaged in the studies on solutions. Ostwald's recognition of the exactness and importance of Sechenov's work by itself placed him in the center of the field.[478] Let us now follow Sechenov in his physico-chemical path.

His first communication on the absorption of carbon dioxide by salt solutions appeared in 1873.[479] By that time, Sechenov had realized that to proceed with the research on the state of carbon dioxide in the blood, he needed to examine the absorption of carbon dioxide by solutions of various salts. As in the blood carbon dioxide was in an "unstable binding" (loose or weak chemical binding) Sechenov selected the analogous salt solutions that had chemical bonding with CO_2 and set up a series of experiments

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[476] W. Ostwald, *Solutions, being the forth book, with some additions, of the second edition of Ostwald's 'Lerhbuch der algemeinen Chemie,'* transl. M.M. Pattison-Muir, London, 1891, p. vii

[477] Arrhenius, however, devoted a whole chapter (III) to the problem of the existence of the hydrates in the solution and specifically to Mendeleev's method. S. Arrhenius, *Theories of chemistry being lectures delivered at the University of California at Berkeley.* London, 1907; German transl. *Theorien der Chemie*, Leipzig, 1906; Russian transl. *Teorii khimii*, St. Petersburg, 1907

[478] Ostwald, *Solutions*, pp. 18, 28-31

[479] I. M. Sechenov, "O pogloshchenii ugolnoi kisloty shchelochnymy zhidkostiami" ["On the Absorption of Carbon Dioxide by Alkaline Liquids"] in *Protok. zased. Novoros. o-va estestvoisnyt.* [Proceedings of the Novorossiisk Society of Naturalists] (1873) 1: 24-31

with them. The new results obtained with the solution of sodium acetate were so unexpected and interesting, that Sechenov decided to continue his investigation with salt solutions. After a set of experiments with seven different salts and the acids in the order of increasing strength, Sechenov assumed that "there was already sufficient material for establishing the general nature of the *weak chemical absorption* of CO_2 by solutions of salts." As Sechenov noted later, he could have stopped his investigations with salt solutions at that point as salts of strong acids did not promise anything for the chemical absorption of CO_2 by the blood.

However, he set up a new set of experiments that aimed to clarify how the composition of the salt solutions affected their absorptiometric characteristics. The results of the experiments showed that the weak and medium concentration solutions of analogous salts absorbed an equal quantity of carbon dioxide. Sechenov asked Mendeleev to present his work at the meeting of the Chemical Society:

> For the salt solutions there exists a simple law: the solutions are equivalent in terms of absorptiometry if they contain an equal percentage of water of crystallization. The second law which results from the first should be formulated in the following way: in the salts of the same structure and containing the same quantity of water of crystallization the chemical equivalents are the same as absorptiometric. As the absorption of CO_2 follows Dalton law, then the numeric data of each separate experiment give solid criteria for all particular determinations. Now I am experimenting with chlorides, which do not contain water of crystallization, and I have already extremely curious facts about which I have to ask your advice. ...Sinner that I am, I even hope to get a place in your laboratory.[480]

In 1875 Sechenov published his work on salt solutions stating, "equivalent weights of the related salts bind equal quantity of CO_2. ... The absorption curve of any salt that binds CO_2 chemically is the resultant of two other curves one of which

[480] Sechenov to Mendeleev, letter d. Odessa, 17 October 1873, in Koshtoyants et al, eds, *Nauchnoe nasledstvo*, pp. 218-9

represents the run of the absorption of CO_2, the other, the run of solution according Dalton law."[481] The same year he presented a manuscript for publication in the *Transactions of the St. Petersburg Academy of Science.* Asking Alexander Butlerov, yet another distinguished Russian chemist of the time, to review the manuscript, Sechenov wrote: "In the area of chemistry I, of course, consulted with the specialists here in all questions which seemed to me doubtful; and although I was convinced of the fairness of all conclusions which I had made, I still have no peace of mind ... for I doubt not for the factual side of the matter. But I maybe too bold in my conclusions."[482]

Sechenov's letters from Odessa to Butlerov demonstrate a concern to get advice and approval of his work in the new field and to share the results obtained in his investigations:

> I am sincerely grateful to you for your advice. From the German manuscript you will see that I have made use of your remarks. I knew the works of Thomsen and Berthelot but in Berthelot's work I miss the fact that heat decreases in saturation of acids by bases to the extent of dilution of solutions, and the decrease is detectable especially in weak acids. For me this fact is the essence of the matter. In view of this fact, all the data of my work could be even predictable. ...I mention this to you as, to avoid hypothesis, I put it bluntly in the German version of the text, that for non analogous salts absorpt[iometric] and chemical equivalents are not equal. Make a note if you agree with this. ... It is difficult for me to give up the fact which might be significant and which has not been easy to work out.[483]

Sechenov spent much time and effort on the improvement of the absorptiometric method which he used in his numerous experiments to obtain the most precise results possible: "...as for the absorptiometry, I swear that I have used the method in hundreds

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[481] I. M. Sechenov, "O pogloshchenii ugolnogo angidrida rastvorami solei" ["On the Absorption of Carbon Anhydride by the Salt Solutions] in *Zhurn. Rus. chim. o-va [Journal of the Russian Chemical Society]* (1875) 7: 214-230 (218)

[482] Sechenov to Butlerov, letter d. Odessa, 14 March 1875, in Koshtoyants et al, eds, *Nauchnoe nasledsvo*, p. 222

[483] Sechenov to Butlerov, letter d. Odessa, 9 April 1875, *ibid.* p. 223

of experiments. The limits of its error are evident, my results are far beyond the error."[484] He was adept in all forms of absorptiometric experimentation, and did not hesitate to refine his absorptiometric apparatus. In another letter Sechenov informed Butlerov about "the arrangement of a new type of absorptiometer that is incomparably more sensitive than the previous one. I have made the model with which trial experiments have been carried out."[485] Having been at the dawn of his scientific career a student of the physiologists who brought experiment, both conceptually and in terms of physical and chemical apparatus, to the center of physiological inquiry, Sechenov sought to "put absorptiometric investigations on a firm basis." The method would be carefully worked out and perfected during multitude of experiments, and the improved version of apparatus adopted for particular kind of measurements with possible maximum precision. Already in St. Petersburg Sechenov was able to order a new instrument from a well-known mechanic at the Pulkovo Astronomical Observatory.[486] The mechanic, whose name we do not know, asked a price of 500 roubles (equivalent to two months' professor's salary), however, Sechenov, who lived almost exclusively on his salary, agreed. He felt that this man was brought up to work with astronomical instruments, which demanded mathematical precision and was right to value such work very highly. The new instrument for absorptiometric studies "met all the conditions stipulated

[484] Sechenov to Butlerov, letter d. Odessa, 14 March 1875, *ibid.* p. 222

[485] Sechenov to Butlerov, letter d. Odessa, 16 Feb. 1876, *ibid.* p. 224. The letter with the description of a new model of absorptiometer has not been located.

[486] Pulkovo Observatory of the St. Petersburg Academy of Sciences was opened in 1839. Friedrich G. Wilhelm Struve (1793-1864), the director of the observatory, was given the resources to buy the very best instruments obtainable, and soon after the observatory was recognized as arguably the leading observatory in the world. It possessed the 15-inch refractor by *Merz &Mahler* (the successors of the famous German craftsman and theoretician Joseph Fraunhofer (1787-1826). The 30-inch refractor from *Repsold & Sons* installed in 1885 was briefly the largest refractor in the world. With such instruments, the management of the telescope reached a new level of sophistication. These great telescopes still exist, now no longer suited to the needs of modern astronomy but preserved as superb examples of the instrument-maker's craft. See, M. Hoskin, ed., *The Cambridge illustrated History of Astronomy*, Cambridge, UK, 2000, pp. 274-5

excellently. The fee, not entirely within my means, was of course quickly forgotten, and then I had only to be glad for the instrument which allow me to trace with certainty the finer things than it was possible with the instrument I had in Odessa."[487]

In 1877 Sechenov published a paper "On the absorption of carbon dioxide by sulphuric acid and its water solutions,"[488] and two years later a monograph *On the Absorption of Carbon Dioxide by Salt Solutions and by the Blood,* where he presented the results of five years research. He demonstrated that in solution of salts on which carbon dioxide could act chemically (for example, sodium salts Na_2CO_3, $Na_2B_4O_3$, Na_2HPO_4), an increase of solubility and deviation from Dalton's law occurred. In solution of sulphate and nitrate salts, carbon dioxide is absorbed in lesser amounts, and the absorption followed the Henry-Dalton law. However, in that case, there was explicit evidence of the interaction between the salt, water and carbon dioxide. Sechenov's notion on the state of substances in solution was close to Mendeleev's: "the more is the attraction of the salt to water, the stronger is hydration and the weaker is dissociation, therefore the absorption of CO_2 should be weak in general."[489]

In 1883 Sechenov started another series of experiments, now with salt solutions indifferent to CO_2. That enabled him to exclude the chemical interaction that distorted the picture of the absorption of carbon dioxide by solution. The results of the study of the absorption of CO_2 by solutions of the electrolytes (NaCl, $NaNO_3$) with decrease of dilution enabled Sechenov to draw a conclusion that "water dissociates a certain amount of salt with the formation of products which absorb CO_2 more strongly than pure water,

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487 Sechenov, *Autobiographical Notes,* p. 151

488 I. Setschenow, "Über die Absorption der Kohlensäure durch Schwefelsäure und deren Gemische mit Wasser" in *Bull. Acad. Sci. St.-Petersb.* (1877) ser. 3, 22: 102-7

489 I. M. Sechenov, *O pogloschenii ugol'noi kisloty solianymi rasstvorami i krov'iu[On the Absorption of Carbon Dioxide by Salt Solutions and by the Blood],* St. Petersburg, 1879, pp. 85-6

and the dissociation increases with increasing dilution."[490] In January of 1886 Butlerov and Ovsiannikov presented to the St. Petersburg Academy of Sciences Sechenov's manuscript "On the Absorption Coefficient of Carbon Dioxide in the Salt Solutions Indifferent to CO_2" in which a law of absorption was demonstrated. That law was expressed in the following equation: $y = ae^{-k/x}$, where y is a coefficient of the absorption of CO_2 in solution; a is a coefficient of the absorption of CO_2 in the water; e is the base of natural logarithms; k is a constant of a given salt; x is the volume in which the salt is dissolved.[491]

Sechenov formulated the importance of the study of distribution of substances in two solvents in the following way:

> 1) it is necessary to determine a general principle of the quantitative classification of salt solutions (that is to say, according to their greater or lesser ability to absorb CO_2 irrespective of their composition) and 2) to find the criteria for the absorptiometric relationship between salt solutions. These attempts could not be recognized as rational because investigations of that type have to embrace thousands of different cases: (the absorption of gas by liquid is dependent on quality and quantity of the composition of the liquid as well as on its temperature). Therefore, we need a classification of salts based on such characteristics as quantity and affinity.[492]

In April of 1887 he presented to the Academy of Sciences another manuscript that continued the manuscript of 1886. The law of the increase of the coefficients of absorption, which had been proved for the solutions of NaCl and $NaNO_3$, was confirmed with another twelve salts (Na_2SO_4, $CaCl_2$, NH_4Cl etc.). For that Sechenov performed more then a hundred experiments that confirmed the existence of two classes of salts:

[490] I. M. Sechenov, " O narastanii koeffitsientov pogloshcheniia CO_2 razzhizhaemymi vodoi solianymi rastvorami," *Zhurn. Russk. fiz.-khim. o-va* (1886) 18 (1): 63-4; 18 (2): 124-8 (126)
[491] I. Sechenov, "Über die Absorptionskoeffizienten der Kohlensäure in den zu diesem Gase indifferenten Salzlösungen," *Mém. Acad. sci. St.-Petersb.* (1886) sér. 7, 34: 1-24 (19)
[492] *ibid*, p. 23

those which absorb a part of carbon dioxide independently of Henry's law, e.g. sodium carbonate, disodium phosphate, borax, etc; and those which exert no definite chemical action on the carbon dioxide, e.g. nitrates, chlorides, and sulphates. The important empirical result of Sechenov's investigations regarding the nature of salt solutions was that solutions containing equivalent quantities of similar salts have nearly equal absorption-coefficients.[493]

Sechenov's investigations on salt solutions were recognized by both leaders of the alternative theories of solutions. He appears to agree with both: regarding one type of salts with Mendeleev and the other, with the 'ionists.' Sechenov's practical results and conclusions did not encroach on the theoretical postulates of either of the theories. It was the solidity and accuracy of Sechenov's methodology in the study of salt solutions that attracted both sides. Mendeleev included Sechenov's results in the chapter on solutions in the fifth edition of his *Principles of Chemistry*.[494] Another influential defender of the importance of hydrates in solution, Marcellin Berthelot, favourably commented and published Sechenov's work in his journal.[495] It seems, however, that Sechenov was particularly pleased with the reception of his work by Ostwald and with the discussion they had during Sechenov's special visit to Leipzig in 1891:

> My visit to Leipzig was a success. My dreams regarding carbon dioxide were recognized as true… Ostwald acknowledged the importance of the absorptiometric method for the study of solutions and regretted that I took salts and CO_2 and in consequence of that the phenomena became complicated by chemical reactions. In his opinion I should have started with gases indifferent to substances in the solution. He believed that a dissolved salt reacted chemically with CO_2 without my experiments. The only thing he does not agree with is my

[493] I. M. Sechenov, *Weiteres über das Anwachsen der Absorptionskoeffizient von CO_2 in den Salzlösungen*, St. Petersburg, 1887, p. 31

[494] D. I. Mendeleev, *Osnovy khimii*, 5 ed., St. Petersburg, 1889, pp. 60-1, 66

[495] I. Sechenov, "Action de l'acide carbonique sur less solutions des sels à acides forts. Etude absorptiométrique," *Ann. chim (phys.)*, sér. 6 (1892) 25: 226-70

interpretation of the absorption of CO_2 by solutions of sulphuric and lactic acids with water. In his opinion, *attraction, affinité* cannot explain the phenomena as neither it nor its effects could be measured.[496]

Apparently it was Ludwig who had introduced Sechenov to Ostwald to help out his friend who was seeking authoritative approval for his strenuous and long work. In his *Lebenslinien* Ostwald vividly described his first meeting with Ludwig in 1887 and Ludwig's friendly disposition towards him, a young man doing his first steps at Leipzig University. Ostwald had highly regard for Ludwig's accomplishments as a laboratory scientist and his kind personality.[497] Judging by the analysis of Sechenov's investigations in the chapter, which dealt with the laws of solutions of his *Lehrbuch der allgemeinen Chemie*, Ostwald appreciated Sechenov's investigation as "it went deeper in the phenomena of salt solutions" than any other study in the field. Two of Sechenov's articles, published in Ostwald's journal, also contributed to a general recognition of Sechenov's work in the chemical community.[498]

In general, then, Sechenov's work was well received; it was adopted into mainstream texts and published in important journals. But Sechenov had hoped for more than this: he had hoped to discover an important unifying law. It seems that in an access of anxious uncertainty, he became obsessed with the recognition of his salt solution investigations. He mentioned in his *Autobiographical Notes* that even his established scholarly reputation "could not eradicate the splinter from his heart," regarding "the fate

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[496] Sechenov to Mechnikov, letter d. Leipzig, 14 April 1991, in Shtraikh, ed., *Bor'ba za nauku,* p. 110
[497] Ostwald, *Lebenslinien,* v. I, p. 267; on Ludwig's laboratory - v. 2, pp. 82-8
[498] W. Ostwald, *Lehrbuch der allgemeinen Chemie,* 2 ed, Leipzig, 1890, p. 78; I. Setchenow, "Über die Konstitution des Salzlösungen auf Grund ihres Verhaltens zur Kohlensäure: Vorläufige Mitteilung," in *Z. phys. Chem.* (1889) 4 (1): 117-25. I. Setchenow, "Analogien zwischen der Auflösung von Gas und Salz in einer zu beiden indifferenten Salzlösung," *Z. phys. Chem.* (1891) 8 (6): 657-60

of his absorptiometric studies."[499] The momentum is best expressed in his letter to Mechnikov: "As you see, I become like poor parents who wish to settle their beloved child. For them he is dear and handsome, but strangers treat him with indifference and suspicion." [500]

Indeed, Sechenov's attitude towards the "fate of his absorptiomentric studies" was extremely sensitive, and in that he appeared a distinctively unusual man. At one point, he felt that he had discovered a general regularity, a law, governing the absorption of gases by salt solutions. His enthusiasm as a researcher is reflected in his letters to Maria Bokova during 1887, in which he described his numerous experiments with excitement and delight.[501] But a year later his mood had changed: it appeared that the law of absorption could be regarded only as a special case. To corroborate the results with gases other than 'eternal' carbon dioxide was technically impossible: "other convenient gases such as oxygen, hydrogen and nitrogen are dissolved weakly, so there was nothing to consider about them." To him, his work had lost its principal significance: he had hoped for a universal law applicable to a "whole class of phenomena." His disappointment was great: he felt that his stay at the University had become "pointless and even unpleasant." To make matters worse, the Minister of Education once again rejected him for a membership in the Academy of Sciences, and then for the title of Honored Professor. These only added to his unhappiness. He sent in his resignation and left, first for his wife's estate and then abroad.[502]

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[499] Sechenov, *Autobiographical Notes*, p. 164
[500] Sechenov to Mechnikov, letter d. Teplyi Stan (Sechenov's family estate in Simbirsk province on middle-Volga), 20 May 1891, in Shtraikh, ed., *Bor'ba za nauku*, p. 111
[501] Sechenov to M. A. Bokova, letters d. St. Petersburg, 29 Aug. 1886, 22 Sept. 1886, 17 Oct. 1886, and 4 Apr. 1887, in Koshtoyants et al. eds, *Nauchnoe nasledstvo*, pp. 256-57
[502] Sechenov, *Autobiographical Notes*, pp 156, 161. Sechenov left St. Petersburg for Moscow by the end of 1888. Next year he began his work first as as a private docent at Moscow University.

One can only imagine Sechenov's disappointment and vexation in view of this utterly unreasonable decision to leave his laboratory and change a professorship in St. Petersburg for a position of *privatdocent*, a junior nobody, at the medical faculty of Moscow University. He was well aware of the poor research facilities of the physiological laboratory in Moscow; moreover he understood that his position here would be insecure for an uncertain period of time. In such a situation he even thought of leaving Russia to work in Leipzig, since Ludwig in his usual sincere and sentimental manner expressed his concern and understanding, reminding to Sechenov that there would always be a room for him in the Leipzig laboratory. Ostwald also had invited him to his laboratory.[503]

Fortunately for Sechenov, he got a chair of physiology at the medical faculty of Moscow University after professor F. P. Sheremet'evskii's sudden death in 1891. It might well be that Sechenov felt that in a new place that happened to be the medical faculty of Moscow University- his *alma mater* – he could be relieved from his disappointment and vexation brought by "the fate" of his absorptiometric studies. New place, new people, new-old problems associated with the arrangement and setting up a physiological laboratory according to his standards and his vision on physiological research and teaching, these are what he sought, moving again from St. Petersburg, this time to Moscow. He wrote to Mechnikov: " I found myself here as in an uncultivated field in which it is easy and simple to bring great benefit."[504] That was his last laboratory and the equipment and arrangement of its work came to be his last contribution to the

[503] Sechenov to Mechnikov, letter d. Teplyi Stan (Sechenov's family estate in Simbirsk province on middle-Volga), 20 May 1891, in Shtraikh, ed., *Bor'ba za nauku*, p. 111
[504] Sechenov to Mechnikov, letter d. Moscow, April 1892, in *ibid*, p. 114

development of the laboratory science in Russia.[505] In some ways it represented for him a fall-back position. Now, whatever his research, his legacy was to be the material culture of these laboratories, in their equipment, their instrumentation, and their teaching programmes.

We can summarize Sechenov's moves from laboratory to laboratory and his intellectual move from one experimental domain to another as an illustrative historical case in the development of nineteenth-century physiology. General moves of ideas, methods, techniques, apparatus, and people from one institution, or country to another was a way of disseminating and constructing the laboratory and science education linked to the immediate economic, military and social needs of the state.

The strong trend of physiology towards the exact sciences which started in the mid-nineteenth century found its best expression in the development of two distinctive investigative streams; the first employed mainly methods of organic and physical chemistry, and the second, the methods of physics and mathematics. Most of the notable physiologists of the second half of the nineteenth century participated in both movements. The unique case is Hermann von Helmholtz's brilliant application of the physical concepts and mathematical methods to the analysis of physiological phenomena, and his transition to the domain where these concepts and methods had originated.[506] Similarly, Lothar Meyer's and Sechenov's physico-chemical research on gases dissolved in the blood, which involved chemical concepts such as acids and bases,

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[505] Sechenov resigned form Moscow University in 1901, four years before his death.

[506] On Helmholtz's influence on nineteenth-century physiology and physics, see the collection of essays D. Cahan, ed, *Hermann Helmholtz and the Foundations of Nineteenth-Century Science*, Los Angeles, 1993

and oxygen and carbon dioxide dissociation mechanisms, led both physiologists to important specialized research in chemistry.

We have explored the suggestion that Sechenov's continuous and strenuous work with the blood gas pump and absorptiometer on the problem of obtaining a specific kind of quantitative information influenced the refinement of specific instrumentation and methods, which themselves suggested or even functioned as an explanatory model for the phenomena under investigation. Precision measurement applied to the problem of blood gas analysis became a driving force for Sechenov in devising the new techniques for his absorptiometric studies on salt solutions. Furthermore Sechenov's move from the problem of blood gases to salt solution exemplified the necessitated transition to the other domain – physical chemistry, in search of the more efficacious explanatory framework for a complex physico-chemical mechanism underlying the respiratory function the living organism.

These intellectual moves within nineteenth-century physiology are manifestations of its gradual transformation into a science, which integrated and bridged the physical disciplines with its concepts, methods, and instrumentation to the investigations of a living organism.

Conclusion

The chapters in the dissertation proceed from a number of traditions that have been exploited in the scholarly work on the laboratory revolution in medicine and on experimental physiology in nineteenth-century medicine in particular. In my discussion of the introduction and development of laboratory medicine to Russia I have covered such aspects as institutional contexts and models, research programs and academic careers, congruent to the state interests. Nineteenth-century laboratory medicine in Russia has not been yet explored systematically by Western scholars, with the exception of the most recent work on Pavlov, which deals with a later period in the development of experimental medicine in Russia.[507] For their part historians of medical education have focused their attention on the development of scientific medicine in *civilian* institutions such as universities. However, the 'Russian case' is of a particular interest, as it demonstrates the close interconnection between the introduction and development of the first Russian teaching and research laboratories and the immediate interests of the military in modernization of military-medical education within the broader context of the liberal reforms of the 1860s followed Russia's defeat in the Crimean war.

There is at the center of the story the institutional history of the St. Petersburg Medico-Surgical Academy, at the time the major intellectual center of Russian medicine. During the first seventy years of its existence the Medico-Surgical Academy shaped its curricula according to the prevailing influence of surgical practice in the field and the then-dominant clinical orientation in hospitals. The great change came after the Crimean war, when the clinical school's classical orientation on anatomy and surgery

[507] Todes, *Pavlov's Physiology Factory*

was replaced by a new orientation towards natural sciences. Botkin's program of scientific medicine and Sechenov's electrophysiological and neurophysiological research programs shaped radically new teaching fields, experimental physiology in particular. A situation similar to that of the St. Petersburg Medico-Surgical Academy had occurred in the Austrian Josephinum. As preliminary research in the *Kriegsarchiv* in Vienna have shown, the period of reorganization of the *Medizinisch-Chirurgische Josephs-Akademie,* or Josephinum started in 1854 during the Crimean war. Austrian military-medical officials, as later their colleagues in St. Petersburg seemed to ascribe to the laboratory the major place in the process of modernization and reformation of their institutions. The nomination of Carl Ludwig to the Josephinum's chair of physiology and zoology, and the creation of the laboratory for experimental physiology in 1855 is particular telling in that respect.

The shift in the St. Petersburg Medico-Surgical Academy's curriculum to the teaching of natural sciences had to meet the concerns of the government for more practical education of physicians: new courses in chemical and physical techniques, microscopy, and physiological experimentation for educational and research purposes; all these were directed to the creation of a new model of medical instruction that proved so successful within German educational system. Furthermore by the reformation of the Academy within broader context of the liberalization of Russian academic life and Russia's openness to West European scientific and ideological influences, the central government provided many opportunities for the emergence of national medical elite of an entirely new sort: research-teaching and publication professorial standard that resulted in the integration of the new methods of exact sciences such as physics and chemistry combined with the traditional anatomoclinical methods into medical teaching and research.

The military-medical authorities had proven particularly receptive to the introduction and rapid expansion of the new research and laboratory facilities at the Academy, therefore the conditions under which the Academy operated proclaimed its superior status. On the other hand, the Universities neglected the existing laboratory facilities during nearly a decade, and funds were not available for the construction of new university-based research laboratories. The university physiological laboratories never achieved the level of funding of the Academy: we have already analyzed the difficulties Sechenov encountered at the universities of Odessa and St. Petersburg - lack of adequate space, insufficient equipment, absence of independent budget or very small budget. I have also mentioned similar difficulties for Mendeleev to finance adequately the University's chemical laboratory. Some of the delays involved in introducing new laboratory and research facilities at the universities, as I have been arguing, can be attributed to the generally unfavourable situation for the state support for the universities after 1866, when growing student unrest brought to an end the first attempts of the government for autonomy and liberalization of the universities.

Historians of German science and higher education have pointed to the pivotal role of governmental support for the development of natural sciences within the medical educational system in the mid-1860s and early 1870s. In Saxony the Minister of Education Johann Paul Freiherr von Falkenstein was responsible for the financial support for the construction of the most famous physiological institute of Carl Ludwig as well as other teaching and research institutes at the University of Leipzig. In Baden the liberal ministry, appointed by Grand Duke Friedrich, spent a substantial sum of money on the laboratories for physiology, botany and zoology, as well as on expanding the existing structures for chemistry and physics at the University of Heidelberg. Friedrich Althoff, Head of the Higher educational section of the Prussian Culture Ministry in the early 1880s was responsible for the unprecedented scale of the creation at the Prussian Universities of research institutes, laboratories, and clinics in the medical sciences.[508] We have seen that in Russia the liberal Minister of War Count Milutin exerted full support for the development of natural sciences and the financing of the Academy's new facilities such as the Natural Sciences Institute and the new physiological, chemical-physical, and clinical laboratories. On the contrary, however, Minister of Education Count Tolstoi embodied the reactionary policy of the state towards the autonomy of universities, which at that stage was decisive for the development of university science. Russian scholarship and the most recent work of Daniel Todes on Pavlov have pointed to the pivotal role of Prince A. P. Ol'denburgskii (1844-1932), a member of extended tsarist family and notable philanthropist, in the foundation of the Imperial Institute of Experimental Medicine in 1890.[509]

The 'Russian case' is useful and enlightening on the important issue of how scientific ideas, research programs and investigative activities pursued in Germany were

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[508] On Saxony see, Lenoir, "Science for the Clinic," Coleman and Holmes, eds, *The Investigative Enterprise*, pp. 139-78; on the University of Heidelberg, Tuchman, *Science, Medicine, and the State*, pp. 138-67; on Prussian universities, see Charles E. Clelland, *State, Society and University in Germany, 1700-1914*, Cambridge, 1980, pp. 280-81; on Helmholtz new physics institute, see D. Cahan, "The institutional revolution in German physics, 1865-1914," in *Historical Studies in the Physical Sciences*, (1985) 15 (2): 1-65

[509] Iu. P. Golikov and K. A. Lange, "Stanovlenie pervogo v Rossii issledovatel'skogo uchrezhdeniia v oblasti biologii i meditsiny," *Pervyi v Rossii issledovatel'skii tsentr v oblasti biologii i meditsiny*, Leningrad, 1990 (7-75); Todes, *Pavlov's Physiology Factory*, pp. 4-12

linked to the similar activities in Russia and how these interactions influenced the development of scientific medicine in Russia. In general Soviet scholarship has neglected the question of what German medicine and science meant in nineteenth century Russia. However, Russian scientists physiologists and chemists in particular, while studying in the West not only became acquainted with what was new in their fields, but also were supposed to report on other countries' achievements to the reformist administration of the Academy as these reports could justify the expenses on the new research and laboratory facilities - a usual practice not only in Russia.

However, understanding of the German influence on nineteenth-century Russian science as transferring knowledge, ideas, instrumentation and techniques seems to be a bit of simplification. I have been arguing that for such scientists as Sechenov, Botkin, and Cyon, Germany and to less extent Paris, were places where their scholarly achievements were recognized, published, and discussed even more then in their own country. It was inevitable: Russian laboratory scientists felt that the research domain of medicine was poorly represented and even more poorly funded in Russian medical institutions. German physiological institutes constituted a well-established network structures within the university system, and German specialized journals were published on a scale still impossible in Russia. German institutions provided for Russian physiologists not only a place in the laboratories but also access to the scientific and academic milieu, that meant for Russia her gradual move towards the Western scientific community, particularly by taking part in the European debates on most of important issues in experimental physiology, physiological and physical chemistry of the time.

The significance of the first wave of institution building for physiology in Russia associated with Sechenov's career first at the Academy and then at the two universities, small laboratories with meager budgets and a limited range of research determined by a set of instruments to pursue such kind of research, was greater than simple moves of the material means such as apparatus or intellectual moves of ideas and methods, identified with the laboratory, from Germany to Russia. These were the first steps towards functionally differentiated physiological laboratories that supported large lectures, practical exercises for all students, and research possibilities for a selected few. It also illustrates a transition towards integrated approaches to the physiological expertise that became dependent on simultaneous development and close cooperation of experimental physiology, microscopic anatomy, and physiological chemistry. The examination of these moves offers us some helpful perspective on the important features in the development of the discipline of physiology, its institutionalization in Russia, and on the interaction between local disciplinary conditions, the governmental attitudes and ideologies, and the investigative efforts of the nascent Russian scientific community.

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