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Historical essay on the 200 years of the development of natural sciences in Russia

P P Lazarev

Towards the end of the 16th century, there emerged a tendency to put an end to the isolation of Russia from civilized European nations. The Russian government made a series of attempts to establish relations with the country's immediate neighbours. Until that time, Russia had had no scientific culture nor even rudiments of science or pseudoscience, such as astrology and alchemy, cultivated by other peoples at early stages of civilization. Those few specialists who showed interest in practical aspects of chemistry and botany were foreigners invited by Moscow tsars to apply scientific expertise to developmental problems. Although certain Russian historians of science (e.g. academician P I Val'den) describe these scholars as direct predecessors of those whom we now call scientists, there is every reason to maintain that no basis for true scientific knowledge had existed in the country until Peter the Great founded the central scientific institution, the Academy of Sciences, in 1725. It is worthwhile to note that the statute of the Academy to be established in St. Petersburg was drawn up by the outstanding philosopher and mathematician G W Leibnitz whose mathematical works created prerequisites for the further brilliant development of exact sciences. Leibnitz is known to have had repeated conversations with Peter the Great who requested the scientist to assist him in his grandiose project for the modernization of the state in the European mode. Relations between the tsar and the prominent scientist turned out to be of great consequence for the future of Russian culture. Leibnitz set to the difficult work of creating a Russian scientific culture with unparalleled ardour, the more so that he had never before confined himself to the interests of his own nation but always thought of the ways to promote the general welfare of mankind. Here is a quotation from his letter to Peter the Great: "I am not one of those who love only their motherland or any single nation. All my thoughts are turned to the benefit of mankind because I consider the Heavens to be my mother country and all sensible persons its fellow citizens. It is more pleasing for me to do a great deal of good for the Russians than a little for the Germans or other Europeans. I would not like the greatest honour, wealth, and fame unless they come for rendering service to others since my ultimate goal is to increase general prosperity." [1] Leibnitz attached great importance to international scientific cooperation which since that time became a major line of activities of the St. Petersburg Academy of Sciences. Indeed, the Academy was constantly involved in research projects arousing great international interest over its 200 year history. Suffice it to mention the studies of V Ya Struve who measured the length of the meridian, notable observations made in the Pulkovo astronomical observatory, metrological investigations of the Central Physical Observatory, and numerous expeditions organized by the Academy. For 20 years, Leibnitz was a key figure in scientific development projects undertaken in Russia and the patron of several expeditions. One of them having far-reaching consequences was V Bering's voyage designed to explore the north-eastern coast of Asia. The primary objective of the expedition was to determine whether Asia and North America were connected by land or separated by a navigable strait which might be used as a sea route around Siberia. In 1725, the Russian government appointed lieutenant V Bering leader of the expedition which eventually passed through what is now known as the Bering Strait. Among other problems in the scope of Leibnitz' interests was a project to establish universities in Moscow, Kiev, and Astrakhan with a mission to train engineers, medical scientists, and secondary-school teachers.

The first members of the Academy were requested not only to develop basic sciences but also to demonstrate their practical applications. Most of them were invited from Germany [2]. It is no wonder that they were virtually unaware of the urgent problems facing Russia. This explains why the foreign scholars who joined the Academy during its early years worked with little concern for handling the country's vital tasks. However, many academicians served as heads of newly-organized laboratories and cabinets staffed by young Russians, unremitting seekers of knowledge. Little by little, a generation of Russian scientists emerged who considered themselves to be charged with the mission of developing scientific research with due regard for the immediate needs and practices of their native country. The culminating figure during this new period was the celebrated Mikhail Lomonosov endowed with limitless creative originality and imagination. His extensive contributions to science include important works on molecular physics, chemistry, electricity, optics, and other branches of knowledge. Through collective effort, these people succeeded in quenching the influence of foreign

This lecture was read by Petr Petrovich Lazarev, founder and first editor-in-chief of *Uspekhi Fizicheskikh Nauk*, at the solemn meeting of the Academy of Sciences which was held in Moscow on 13 September 1925 to celebrate the 200th anniversary of the Russian Academy of Sciences. The lecture was first published as a booklet in only 500 copies by the Academy's publishing house in Leningrad (1926). The portraits of scientists in this paper were made by P P Lazarev.

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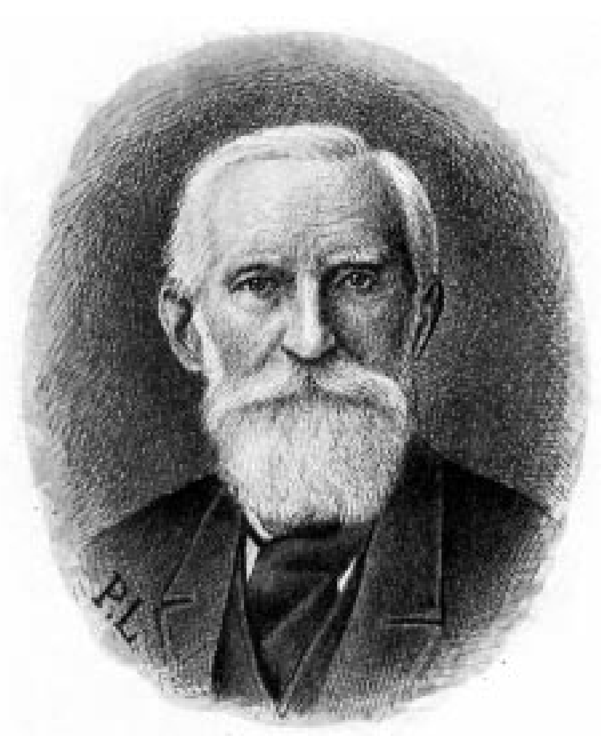
[1] W Guerrier *Leibniz in seinen Beziehungen zu Russland und Peter dem Grossen* (St. Petersburg, 1873) S. 208.

[2] Listed among the first members of the Academy (1725 – 1733) were 20 persons from Germany, 5 from Switzerland, 2 from France and only one (V E Adadurov) from Russia.

L Euler

academic scholars and thus promoted reforms to make science more closely linked with the life of the country of which Lomonosov was a lifelong champion. To that end, much importance was accorded to applied sciences, and Lomonosov began prodigious activity to set up a variety of chemical works which enabled him to lay the foundation for the production of glass and other materials. This celebrated his fruitful union of abstract and applied science which, since that time, has ever remained an inherent feature of research projects undertaken in Russia even though it not infrequently met with strong opposition. Anxious to carry out research on a broader and regular basis, Lomonosov cherished the idea of establishing a scientific school. He courageously faced the ill will and hostility of his influential dissenters when he first requested a laboratory to accomplish this purpose. In the end, however, he was granted it and made it the first laboratory in which the methods of chemical research were systematically taught to young students. This laboratory existed long before the world famous laboratory in Giessen established by Justus von Liebig who is supposed to have set the pattern for chemical education that later came to be the prevailing system. To these achievements, Lomonosov added the work of reorganizing popular education of which he was a lifelong champion. He understood that scientific progress was impossible without a broad intellectual public. In parallel to a series of public lectures delivered at the Academy, Lomonosov followed very closely the development of a university, the first institution of higher learning in the country, which was to become the main source of systematic training of young people seeking a scientific career in a range of disciplines. This idea directly ensued from what Leibnitz had suggested for the development of education in Russia. The efforts of Lomonosov in this area were supported by I I Shuvalov whose patronage was instrumental in establishing Russia's first university in Moscow. This was a way to distribute scientific knowledge and create a tradition of educational opportunity for many. The foundation of Moscow University greatly spurred the growth of the country's university system. State universities continued to be established by the Russian government including those at St. Petersburg, Kazan, Kiev, and Kharkov. Many of them soon became the most important centres of scientific research and scholarship and still retain their preeminent position. The importance of scientific results obtained at university laboratories in different parts of Russia can be illustrated by the progress in a single discipline, such as chemistry. Indeed, the main scholarly journal of the *Russian Physico-Chemical Society* founded by D I Mendeleev gradually succeeded in drawing greater participation of researchers while more and more chemists attended professional meetings which eventually raised them to international prominence. Many university laboratories became important international scientific centres that were able to compete on virtually an equal footing with the laboratories of the Academy and scientific institutions in other European countries. Universities played a major role in the development of chemistry, physics, biology, and geology as self-contained scientific disciplines. It is safe to say that since that time each branch of knowledge has had a specific area of research and its own choice of methods. During this 'university period' in the history of Russian science, it attained considerable prestige abroad. Equally important studies were simultaneously carried out in academic laboratories, and the majority of distinguished scientists working in university laboratories and cabinets were members of the Academy of Sciences. Thus, the initial 'academic period' was followed by the 'university period' during which the activities within the Academy of Sciences were paralleled by the evolution of a large number of newly-organized non-academy research centres of which many were held in high esteem not only in Russia but also in the outside world. This had resounding repercussions on the intellectual



P L Chebyshev

A M Lyapunov

development of the nation. A large number of teachers, engineers, specialists in medicine and law were educated at institutions of higher learning formed on the model of the Moscow University founded by M V Lomonosov. A large number of investigations during this second period were accomplished in university laboratories which also served as research-study schools for young scientists.

The evolution of new scientific disciplines and complicated methods of research pose serious problems for investigators. The necessity to develop sophisticated experimental techniques and expand the scope of research require the organization of institutes for these specific purposes. This new trend is equally apparent in Europe and America, and also in Russia. The first institutions of this type established in the pre-war † period were the Research Institute in Moscow which was to study exact sciences and the Institute of Experimental Medicine in St. Petersburg to carry out medical investigations. A large number of new scientific institutions arose and expanded their activities after the end of hostilities and the revolution. Many of them were organized under the patronage of the Academy of Sciences (e.g. the Radium Institute, the Platinum Institute, the Physico-Mathematical Institute, etc.). Some of them later became autonomous research bodies (e.g. the Optical Institute).

Considering the parallel evolution of science in this country and in the rest of the world, one should first of all evaluate the results obtained by Russian researchers during the period of interest and their importance for the progress of human knowledge.

Let us start with mathematics which, in this country, has been developing on the solid basis laid by the first members of the Russian Academy of Sciences. Leonhard Euler, a man of genius, was among the pioneering foreign scholars who worked in the Academy in its early decades. He first came to Russia from Switzerland when he was very young. Euler's exceptional intelligence and remarkable power of working enabled him to study physics after he had satisfied his interest in medicine and finally devote himself to pure mathematics. In this area, he was the first to accomplish the difficult task of elaborating the principles of both integral and differential calculi and carrying them to a higher degree of perfection on a sound foundation laid by the original discoveries of Newton and Leibnitz in the analysis of infinitely small quantities. Euler's brilliant textbooks in calculus served as prototypes to many others on the subject up to the present time. From his study of maxima and minima under the most complex conditions, Euler deduced the first general rules for the calculus of variations. An elegant solution to many remaining problems known to be of primary importance for the application of mathematics to physics and mechanics was later found by Russian mathematicians. Newtonian mechanics first applied to simple problems remained, till Euler addressed the subject, an essentially geometric discipline as it had been originally formulated by I Newton. Euler made the first brave attempt to apply the novel mathematical methods to the study of mechanics and thus laid the foundation of modern analytical mechanics. Problems related to the rotation of a solid body and fluid motion exemplified the application of the methods of this new mechanics to various scientific disciplines. Finally, many problems of mathematical physics were found to have a complete analytic solution. By way of example, Euler was the first to develop the system of geometric optics with all its applications. Also, he tried for the first time to use mathematical analysis in physiological studies. Then he carried out unparalleled investigations into the mechanism of blood flow in the vessels which justifies reckoning him among founders of modern biophysics. Euler demonstrated

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† Here and hereinafter, the author alludes to the First World War. (*Note by the translator*.)

M V Lomonosov

useful applications of mathematics in various branches of technology and public affairs. Worthy of special note are his remarkable studies on the theories of ship building, vibration, elasticity, hydraulic turbines, etc. Euler was the head of the Russian mathematical school. It is known that young mathematicians, his students and assistants, helped Euler in his work on the theory of lunar motion.

The scope of Euler's interests covered almost the entire range of topics pertaining to pure and applied mathematics. His works stimulated an enormous amount of studies on the same subjects. However, Euler did not confine himself to research and technical development projects. In his equally deep concern for educational problems, Euler wrote a few textbooks for secondary schools including a classical treatise of algebra. Finally, we owe Euler a remarkable popular science book, an admirably clear exposition of the basic principles of exact sciences in the form of letters to a German princess. The book fully retains its interest for readers as a valuable source of information.

The scientific works of Euler earned him a high reputation both in Russia and abroad. Here are a few extracts from the brilliant oration on the death of Euler delivered by the celebrated Marquis de Condorcet to the Paris Academy of Sciences. "All outstanding mathematicians who live today are Euler's students. There is no-one among those receiving a mathematical education who does not study his works, who does not use his formulas or his method. Everyone carrying out research is guided and supported by the genius of Euler. He earned fame from the revolution in mathematical sciences which he subjected to analysis. Also, he owes his fame to an uncommon zeal and amazing efficiency in applying his intellect which allowed him to explore all areas of mathematics and present a synthesis of knowledge covering this vast and complex field. He did his great work with good order and discipline, his formulas are simple and elegant, proofs and arguments are clear and convincing, the more so that they are supported by carefully selected examples. Neither Newton nor even Descartes, despite his pervasive influence, enjoyed such great personal fame as did Euler in his own lifetime, and to this day only Euler retains it so wholly and indivisibly". This is how Condorcet describes Euler's situation in Russia: "The Russian government never regarded Euler as a foreigner... His death was considered to entail an irreparable loss for the country where he lived. The St. Petersburg Academy of Sciences greatly honoured him with an impressive funeral and allocated funds to have his portrait bust sculptured and placed in one of its meeting halls. He had received even higher honours from the Academy during his lifetime". "Thus it is", Condorcet concludes, "that the country at which we used to look at as still remaining barbarian, by the turn of this century teaches the most enlightened nations of Europe how to revere great persons and their memory".

Such a personality as Euler's could not but exert an important influence on the mathematical thought and future studies in Russia. There is a strong mathematical school in the country whose basic directions in many respects continue his own works.

Two other contemporary mathematicians of Euler's time closely tied with the Academy during its early period were Nicolas and Daniel Bernoulli. Daniel's reputation was established in 1738 with *Hydrodynamica* in which he considered, for the first time, the properties of basic importance in gaseous matter and interpreted them in terms of the kinetic theory of gases.

The most important figure among the outstanding scholars considered to be Euler's disciples was M V Ostrogradskiĭ, the leading Russian mathematician of his day, who exercised profound influence on the development of this science in the country. Ostrogradskiĭ kept his interest focused on mathematics, mechanics, and mathematical physics. The most important of his mathematical studies are classical works on the calculus of variations. A 28-page synopsis of these studies can be found in the well-known book of Totgenter *History of Achievements in the Calculus of Variations* (pp. 111 – 139). It is beyond the scope of the present communication to list all works of Ostrogradskiĭ. Suffice it to mention the large number of mathematical theorems discovered by this author. For the sake of illustration, there is a famous transformation of a triple integral into a double one which is of crucial importance in mathematical physics (hydrodynamics, the theory of heat, electricity, and magnetism). Also, this transformation underlies the Maxwellian theory of local action in electricity. This notable transformation was discovered by M V Ostrogradskiĭ [3].

The most interesting works of Ostrogradskiĭ in the field of mechanics concern investigations into the motion of an elastic body and the development of methods for integration of the equations of dynamics. In these areas, Ostrogradskiĭ continued the studies of Euler and the outstanding French mathematicians Lagrange, Poisson, and Cauchy; he formed a close friendship with some of them. M V Ostrogradskiĭ is recognized as a foremost contributor to the development and achievements of the Russian mathematical school. He was one of the first Russian mathematicians working in France

[3] Maxwell wrote in his famous *Treatise on Electricity and Magnetism*: "This theorem appears to have been derived for the first time by Ostrogradskiĭ in a paper read before the Academy of Sciences in 1828 and published in 1831". (volume 1, p.117, Oxford, 1871).

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with distinguished scientists. He established close links between Russian and French mathematicians and thus began a tradition which continues to the present day. Studies of Brashman and Davidov on the stability of a floating body and especially the brilliant works of N E Zhukovskiĭ on aerodynamics and hydrodynamics exemplify further development of Euler and Ostrogradskiĭ's ideas. Finally, Russian engineers made an important contribution to the practical application of mathematics in those fields which had been most thoroughly elaborated by Euler and Ostrogradskiĭ.

Further progress in mathematics in this country is associated with the names of P L Chebyshev and A M Lyapunov. Chebyshev is remembered primarily for his studies on selected aspects of the analysis of infinitesimals and, in particular, the calculus of variations. His mathematical writings covered a wide range of difficult subjects, including the theory of probability and many aspects of applied mathematics of great practical significance. His activity as professor of mathematics at the University of St. Petersburg and his numerous scientific works made him widely known in the mathematical world. This historical review of the development of mathematical sciences would be incomplete if we did not mention the principal work of Lyapunov concerning the shape of a fluid body in rotational motion, with Newtonian forces of attraction acting between its particles. This difficult problem of great theoretical interest leading to new methods of mathematical analysis has just as important practical implications because the shape of a fluid in rotational motion has a direct bearing on the question of planet shape which in its turn is essential for higher geodesy. Lyapunov proposed a brilliant solution of the extremely complicated problem of fluid stability. He demonstrated that certain stability figures form an unstable system tending toward a new stability state upon the separation of a satellite. This problem acquired great importance in cosmic physics which has recently proposed a theory of evolution of stars and stellar systems based on the ideas of Poincaré, Darwin, and Lyapunov.

Up to this point, we were almost exclusively concerned with research devoted to pure analysis and its applications which continued Euler's works and gave a brilliant illustration of the application of mathematics to the study of nature. Let us now turn to geometrical problems that were first solved in Russia. The leading figure in this area was the mathematical genius N I Lobachevskiĭ considered to be the founder of new non-Euclidean geometry. Lobachevskiĭ formulated the basic principles underlying geometry. Specifically, he showed that Euclid's parallel postulate could not be deduced as a consequence of his other postulates and that it was an empirical matter to determine the nature of space. According to Lobachevskiĭ, a non-Euclidean geometry as consistent as a Euclidean one was logically possible. This form of geometry implied the existence of a space different from Euclidean space in that it admitted the possibility that there were at least two lines through a point not on a given line parallel to that line. This discovery demonstrated for the first time that geometry is essentially an experimental science and the most exact one of all experimental sciences. In addition, the splendid works of Lobachevskiĭ suggested the possibility of a number of spaces with properties differing from those of our Euclidean space. His ideas were further developed in the studies of Riemann, Helmholtz, and Lie. Moreover, the same investigations into non-Euclidean geometry played a fundamental role in the mathematical formulation of relativity theory by A Einstein.

Turning from pure and applied mathematics to experimental sciences, it is worthwhile to mention the distinguished role of Russian scientists in the development of astronomy and geodesy. To begin with, it is appropriate to mention a study undertaken under the guidance of V Ya Struve which resulted in the measurement of the length of the meridian extending over 25 degrees of its arc. Measurements using the method of triangulation were made in the northernmost areas of the globe and brought valuable data for the determination of the Earth's shape. Since that time, each geodetic treatise describes this notable study and gives a detailed account of its results. This work was continued at a much greater scale after the death of V Ya Struve. It was largely the responsibility of the Corps of Military Topographers which carried out extensive geodetic and cartographic surveys having the most important repercussions on refining knowledge of the geometric figure and dimensions of the Earth.

Astronomical observations of unprecedented scope were undertaken at the Pulkovo Observatory. The findings were published in the famous catalogue, one of the classics of binary-star astronomy. Equally original and precise methods were used to measure stellar parallaxes. Finally, measurements of the stars' velocity as derived from the Doppler frequency shift exemplified another brilliant application of astrophysics. It is worthwhile to note that the first physical investigation into the Doppler effect for the purpose of optical sensing was also accomplished in Pulkovo by A A Belopol'skiĭ. An in-depth study was later performed by B B Golitsin.

F A Bredikhin developed cometary tail kinematics based on the fact that the tail matter undergoing attraction in agreement with Newton's law of gravitation is at the same time subject to the action of a repulsive force deflecting the tail away from the Sun and obeying the same law, that is varying inversely as the square of the distance to the Sun.

P N Lebedev demonstrated experimentally that the repulsion must be a function of the solar light pressure on gas molecules. His accurate measurements showed that light exerts a minute pressure both on bodies, as predicted by Maxwell's electromagnetic theory, and on individual gas molecules. Not only is this remarkable study of great interest because it confirms the theory of Maxwell, but it also laid a foundation of the concept of variable mass depending on motion velocity which forms a fundamental principle of modern physics.

We now turn to a science in which the supreme achievements of Russian investigators are universally recognized and which is believed by many to stand at a pivotal midpoint between exact sciences. This science is formed from two originally separate but currently merged disciplines, molecular physics and chemistry. The idea to explain both physical and chemical phenomena based on the molecular structure of bodies belongs to the first Russian scientist M V Lomonosov. According to Lomonosov, there are a limited number of chemically unalterable bodies (elements), isolated particles of which, indistinguishable to the naked eye, possess element-specific properties. Any natural substance is actually a combination of such invisible particles (atoms) which are generally speaking in constant motion rather than at rest. Atomic motions are responsible for heat phenomena. Based on these simple postulates, Lomonosov explains not only physical processes but also the synthesis of chemical compounds. In his widely known book *Elementa Chimiae Matematicae* (Elements of Mathematical Chemistry), Lomonosov suggests an atomistic theory which not only underlies most of chemistry but also unifies a great deal of modern physics. Its principal propositions are so up-to-date that they seem to be borrowed from a modern treatise on molecular physics. It is worth citing a few extracts from this book by Lomonosov (substituting current terminology for obsolete terms) [4].

"Definition 37. An atom is a part of a body containing no smaller bodies differing from it.

Definition 38. The molecule is an agglomeration of atoms into one minute mass.

Definition 39. Molecules are uniform if they consist of an equal number of the same atoms bonded in a similar mode. Molecules are non-uniform when their atoms are different and bonded in different ways or in a different number. Hence, an infinite variety of bodies.

An element is a body composed of uniform molecules. The compound consists of two or more elements linked in such a way that the parts of each individual molecule are in exactly the same proportion to one another as the elements are in the entire compound."

It appears from these definitions that Lomonosov developed his theoretical views to a point that puts him on an equal footing with modern scholars. Also, it should be emphasized that Lomonosov presents a detailed description of the properties of atoms and molecules in a paper entitled "O Sostavlyaushchikh Tela Prirody Nechuvstvitel'nykh Fizicheskikh Chastichkakh, v Kotorykh Nakhoditsya Dostatochnoye Osnovanie Chastichnykh Svoistv (On Invisible Physical Particles which Form Natural Bodies and Account for Particle-Like Properties)".

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"Definition 52. Physical bodies can be divided into the smallest units invisible to the naked eye; in other words, these bodies consist of non-identifiable physical particles.

Definition 55. Individual physical particles have length.

Definition 58. Individual invisible physical particles have inertia.

Definition 59. Each particle consists of a certain amount of matter because the force of inertia is proportional to the amount of matter.

Definition 60. Particles are mutually impenetrable.

Definition 69. Whenever there is a change in the bodies' particle-like properties, the inevitable result is the combination, separation or transfer of invisible particles; but no change of bodies is possible without motion. Although no motion is normally perceptible, invisible particles combine, separate or undergo transfer by virtue of imperceptible motion.

Definition 70. Because the particle-like properties of bodies change with the combination, separation or transfer of constituent particles, they depend on invisible particles.

Definition 72. Particle-like properties are due to the length, force of inertia, and physical motion of invisible particles.

Definition 77. Particle-like properties of bodies can be explained in terms of the laws of mechanics" [5].

The spectacular ideas of M V Lomonosov can be fully appreciated if compared with current concepts dominating modern chemistry and physical chemistry. It is easy to see that modern treatises of chemistry expound the atomistic theory in essentially the same terms which Lomonosov used to describe his ideas. But Lomonosov went a step further than his

[4] Lomonosov' terminology is inconsistent and varies from one publication to another. He uses the word 'element' for 'atom' and writes 'corpuscle' instead of 'molecule'.

[5] *Elementa chimiae mathematicae*. Complete Works of M V Lomonosov, vol. VI, p. 23.

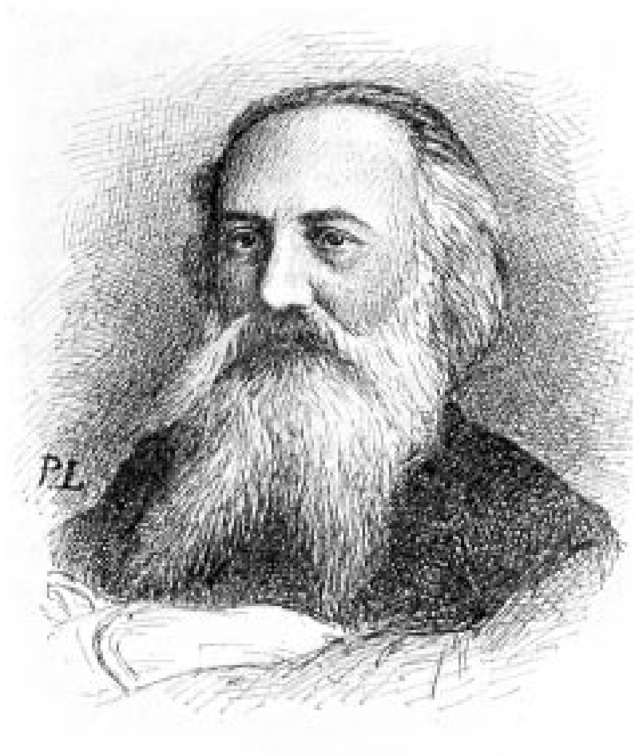
contemporaries and successors, the step which was actually made anew only in our time. Indeed, he ventured to combine chemical and physical atomistic concepts into one theory. Lomonosov's works on the molecular properties of bodies were closely connected with his ideas which formed a basis for the mathematical theory of heat. This theory directly ensued from Lomonosov's studies in the field of molecular physics and was inserted into the "Meditationes de Calories et Frigoris Causa (Reflections on the Cause of Heat and Cold)" (1744 – 1747). This is how Lomonosov wrote exposing his great thoughts: "The corollaries from our theory are as follows. Particles of warm bodies rotate faster and those of cold ones slower. A warm body cools upon contact with a cold one because the thermal motion slows down. Conversely, a cold body may be heated by bringing it into contact with a warm one due to a more rapid thermal motion" [6].

To better understand Lomonosov's views it is appropriate to recall an important work in which he discussed the theory of the elastic force of air (1745). He set forth his ideas in the following way: "There is little doubt that particles of the air tending to drift apart under the action of an elastic force are devoid of any physically organized structure and must be very hard and resistant to modifications to be able to undergo such changes and exert surprising actions. For this reason, they should justifiably be called atoms" [7].

It can be seen that the same properties of atoms are implied by the kinetic gas theory; also, the current concept offers essentially the same explanation of gas pressure as was given by Lomonosov. The mechanical theory of heat suggested by Lomonosov is an important generalization of those views of Daniel Bernoulli which he formulated during his work in St. Petersburg and published in Latin in the *Hydrodynamica* (Hydrodynamics or Commentaries on Forces and Movement of Fluids) (1738). Lomonosov's pioneering experimental verification of the gas expansion postulate which stemmed from his own theoretical propositions had given practically the same value of the expansion coefficient as was obtained later using more sophisticated techniques. Lomonosov hypothesized that atoms of elements changed places with one another during chemical transformations and argued that the mass of the substance had to remain unaltered after a chemical reaction. He thus furnished a clear statement of his principle of the conservation of matter in chemical reactions, the universal law of modern chemistry. In order to experimentally check the validity of his theory, Lomonosov made two bodies interact in a sealed tube where an induced chemical reaction resulted in the synthesis of new compounds. The weight of the tube being the same before and after the reaction, Lomonosov concluded that the weights of the bodies (hence, their masses) did not change. Lomonosov performed this experiment which constitutes the foundation on which modern chemistry existed a few decades earlier than A-L Lavoisier. Therefore, he, together with Lavoisier, should be considered the fathers of this science. Interestingly, this Lomonosov's postulate allows other laws of nature to be theoretically deduced. Indeed, they were later derived by Dalton, Gay-Lussac, and many other researchers. These works of Lomonosov in the field of the molecular theory give a classical example of great creations far ahead of their time. There is little doubt that the advanced character of his findings was the main reason for which they were not immediately recognized at their true worth by contemporaries [8].

[6] *Meditationes de Calories et Frigoris Causa* Complete Works of M V Lomonosov, vol. VI, p. 45.

[7] *Tentament Theoriae de vi Aeris Elastica* Complete Works of M V Lomonosov, vol. VI, pp. 83 – 84.



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Nowadays, chemists recognize Lomonosov as one of the greatest scientists. For example, Schpetter writes in his *Essays on Lomonosov's Predecessors*: "It may be proposed with a high degree of probability that if Lomonosov had lived at the time of Lavoisier and focused all his attention on purely chemical problems, he would have achieved the goal as easily as Lavoisier". The introduction to the collected works of Lomonosov in Ostvald's Classics edition ends with the following phrase: "Lomonosov's clear thought produces a feeling of satisfaction in lay readers of his historical writings".

Studies of elements and their properties led to the discovery of some general rules concerning elements that form similar compounds. However, the law governing the behaviour of all chemical elements remained to be found. D I Mendeleev is credited with bringing order and clarity out of the chaos that prevailed in studies of the elements before him. Mendeleev developed the first rational classification of

[8] Characteristically, even in Russia, the motherland of M V Lomonosov, the many progressive-minded people from his time until now have proved unable to understand the importance of the works of this many-sided genius who equally contributed to the development of physics and chemistry. For the sake of illustration, here is a quotation from A N Radishchev's book *Puteshestvie iz Peterburga v Moskvu* (A Journey from St.Petersburg to Moscow)": "To follow the truth, let us not see a great annalist in Lomonosov. He is no match for Tacitus, Raynal or Robertson, nor even Markgraf and Rudiger, because he kept his interest focused on chemistry. He loved his chemical studies and devoted much of his life to the search for the laws that govern nature. But his ways were those of a continuer. He roved over well-trodden paths and failed to find a blade of grass in the boundless realm of nature which had not been looked at before by his betters".

K von Baer

chemical elements based on their atomic weights. In volume 1 of his famous *Osnovy Khimii* (Principles of Chemistry) (1869), Mendeleev devised a tabular arrangement of all elements in order of increasing atomic number and according to a distinct periodicity of their properties. The resulting table did not only show and make it possible to observe many types of chemical relations between known elements. It also predicted the existence of elements not yet discovered and foretold their main characteristics including the exact atomic weight. Moreover, Mendeleev's classification provided a logical order of known elements to more precisely determine their atomic weights from chemical properties. Indeed, Mendeleev was the only chemist of his day who attempted to obtain the true atomic numbers of elements. He inserted necessary corrections into the very first edition of the 'Principles of Chemistry'. Therefore, the new law proposed by Mendeleev provided an effective tool for correlating the properties and the atomic weights of chemical elements. The periodic table had gaps which, according to Mendeleev, would be filled by elements not then known. The great value of the periodic system was made evident by the discovery of new elements which confirmed its importance for the analysis of the observed relationships. Since that time, chemistry has obtained the status of an exact science which it maintains till now. Mendeleev's periodic table became the framework for a greater part of modern physical and chemical theory and proved to be most useful in the search for new elements and the interpretation of their atomic structure.

Studies of capillary attraction at the surface of a fluid at different temperatures led Mendeleev to the discovery of the law which describes a change of intermolecular forces that operate in a fluid medium. He demonstrated that there was no attraction between particles of the fluid at a specific temperature and concluded that under such conditions particles could easily drift apart. This temperature, which Mendeleev called the absolute boiling temperature, was referred to as the critical temperature by subsequent authors. Evidently, no work is needed to support evaporation at this temperature. Further studies conducted by M P Avenarius, A I Nadezhdin, Zaĭochevskiĭ, A G Stoletov, and B B Golitsyn provided a wealth of new data on the subject. As a result, Russian scientists turned out to be the most important contributors to the collected works on critical temperatures published at that time by Landolt. Corollaries from Mendeleev's theory emphasized its practical usefulness. It should be recalled that the liquefaction of air, hydrogen, and helium upon cooling to ultralow temperatures became possible due to the knowledge of the corresponding critical temperatures. This is only one illustration of the value of Mendeleev's findings in this area.

Mendeleev proved equally efficient when he turned his attention to the theory of solutions. In his studies of aqueous alcohol solutions, Mendeleev hypothesized that abrupt changes in their physical properties could be accounted for by the appearance of hydrates which gave rise to peculiar chemical compounds dissociated in the solutions. This hypothesis was developed by Mendeleev independently of the theories of J H van't Hoff and S A Arrhenius applicable only to diluted solutions. In contrast, the results obtained by Mendeleev enabled him to explain the properties of strong solutions. Subsequent investigations provided a solid experimental basis for his theory.

A M Butlerov was a pioneer of structural research in organic chemistry. His ideas of molecular structure and the interrelationship of atomic bonds were further developed in the works of his numerous pupils. N N Zinin, E E Vagner, N A Menshutkin, V V Markovnikov, L A Chugaev, and some others conducted and published studies which made them classical authors in organic chemistry.

A O Kovalevskiĭ

I I Mechnikov

We have already mentioned that the foundation of the modern physico-chemical theory was laid by M V Lomonosov. Now, it is worthwhile to note that thermochemistry owes as much to the classical works of G H Hess while E I Parrot carried out an in-depth study of the mechanisms of diffusion and left a detailed and precise description of this phenomenon which is considered to be a most valuable contribution to physical chemistry.

To conclude the review of achievements of Russian scientists in this branch of knowledge it appears appropriate to recall the splendid results obtained by J Gadolin and E S Fedorov in their structural studies of crystals. These works brought about as valuable knowledge as that obtained by the founders of scientific crystallography. They form the geometric basis for the development of this discipline at the present time.

The discussion of purely physical research immediately brings to mind the notable studies of P N Lebedev concerning the interaction of resonators. Based on his findings, Lebedev suggested that effects exerted by molecules containing resonators could be explained in terms of interactions between resonators themselves. He used this approach to briefly describe the process of diffusion, the behaviour of chemical compounds, and other phenomena.

The interaction of light with matter as well as its resulting effects was minutely examined by many Russian physicists. Light is known to produce thermal and mechanical effects, the latter being due to the pressure of incident light on a body. Furthermore, light induces the emission of electrons (photoelectric effect) and, finally, triggers numerous chemical reactions. It has been mentioned above that light pressure was discovered by P N Lebedev. A G Stoletov studied the photoelectric effect in that elementary form which is now regarded as classical. Some of those interested in photochemical processes are presently recognized as founders of modern photochemistry (e.g. T Grotthuss). Winding up the discussion of light studies carried out by Russian scientists, one can not help drawing the readers' attention to a paper by N A Umov in which the author presented a mathematical description of the movement of energy in bodies. The outstanding role of his ideas in modern physics became apparent after the publication of J H Pointing's works.

In conclusion, there are a few more findings of Russian scientists which had important repercussions on the further development of physics. V V Petrov much earlier than H Davy observed the voltaic arc, and P N Yablochkov used this phenomenon to construct the first arc lamp (Yablochkov candle). B S Jacobi made a discovery of great practical value which led him to the invention of galvanoplasty. Furthermore, E Ch Lenz formulated the classical law of induction and investigated thermal effects of electric current. These studies brought him a world reputation.

B P E Clapeyron and G Lamé, professors in St. Petersburg, were the most renowned foreign scientists working in Russia during the period of rapid progress in mathematical sciences (1810 – 1840).

Cosmic physics was one more discipline which developed at a fast pace in Russia. The establishment of the Central Physical Observatory in St. Petersburg provided the possibility for Russian scientists to participate in international geophysical projects. The works of A Ya Kupfer, G I Vild, and B B Golitsyn who consecutively headed the Observatory did not only lead to the development of new methods for geophysical surveys (e.g. magnetometry, seismometry, etc.) but also greatly helped advance theoretical studies in the respective branches of knowledge.

The supreme achievements of Russian scientists in physics and chemistry were paralleled by just as impressive progress in biological sciences. Russian biologists made a series of fundamental discoveries of primary importance for the

I M Sechenov

N I Pirogov

understanding of many aspects of plant and animal life. To begin with, Caspar Fridrich Wolff and Karl von Baer, founders of modern embryology, were members of the Russian Academy of Sciences and worked in its laboratories. The fundamental principles of comparative embryology, such as the existence of a common pattern in the embryological development of a wide variety of multicellular animals, were established by A O Kovalevskiĭ, I I Mechnikov, and V V Zalenskiĭ in Russia; their works are referred to in all important textbooks on embryology. In other fields of biology, N I Pirogov is widely known for his anatomic studies, precise description of many human organs, and development of a reliable method for their location. Before the remarkable discovery of W H Roentgen, this method provided a unique possibility to study the interrelationship of different organs. Apart from their great theoretical value, Pirogov's works were conducive to the development of clinical surgery. Specifically, his atlas of anatomy was considered to be the most valuable and comprehensive source of human anatomic data till the end of the last century. In physiology, I M Sechenov performed a series of brilliant studies on blood gas composition and exchange and on inhibitory effects of nervous system. Just as important, if not more so, were the extensive studies of I P Pavlov on digestive secretions and his concept of the conditioned reflex. Phytophysiology owed much of its success to the remarkable works of A S Famintsyn who was the first to offer a rational explanation for the processes of matter conversion in plant tissues. An enormous amount of work was painstakingly done to have minute descriptions of Russian flora and fauna and periodically revise them to maintain their scientific value. The morpho-physiological studies of L S Tsenkovskiĭ, M S Voronin, and S N Vinogradskiĭ laid the foundation of new biological disciplines.

Russia occupies one seventh of the Earth's surface area. The geographic features and geologic conditions of its European part were thoroughly explored by Russian scientists. In connection with this, the works of P S Pallas, a world-renowned naturalist and traveller, are worthy of note in the first instance. His activity was held in high esteem not only in Russia but also abroad. Here is a citation from a speech of another celebrated scientist, G Cuvier, delivered after Pallas' death: "When a man totally devotes himself to science, when his entire life is occupied by observation and description, and he undertakes a new study as soon as he publishes the results of the previous one, then his life may seem generally uninteresting and easy to understand from the analysis of his works. But if a scientist, working for his peers in search of new facts, also does his best to present them in the most simple and clear form to enable others to easily draw their own conclusions, then it is useless to analyse his works simply because they must be read from the beginning to the end. Pallas was such a person". Pallas exerted a profound influence on the geographic and geologic exploration of Russia, and his name can be ranked with the greatest names of his time. The early period of geographic and geologic surveys in this country owed its achievements to the activity of the Academy of Sciences. Geological investigations under more favourable conditions were further promoted due to the establishment of the Geological Committee. Especially remarkable progress was apparent during the period from 1882 to 1925. To compare, there were only 10 scientific missions and trips in 1882, almost 30 in 1902, and about 180 in 1925. Materials collected under the auspices of the Geological Committee were used to compile a geological map of European Russia. The Asiatic part of the country remains virtually unexplored and is a promising area for future studies.

P S Pallas

Till this point, we have largely been speaking about pure science paying little attention to its practical applications. Meanwhile, Russian investigators were equally efficient when they attacked both basic and applied problems. By way of example, M V Lomonosov carried out very important studies in the First Chemical Laboratory which were subsequently used in different areas of chemical technology. More recently, D I Mendeleev spent much time working on the development of the Russian chemical industry and was a recognized expert in this field. He published several books on the subject. The same issue was addressed in a series of fundamental studies undertaken by A M Butlerov, N N Zinin, and other Russian chemists. Russia's greatest natural wealth being derived from petroleum, oil was traditionally an object of great interest and numerous studies of several Russian chemical schools. These studies demonstrated the difference between Russian and American oil and offered a scientific explanation. N E Zhukovskiĭ earned a world reputation for his brilliant works of primary importance for applied mechanics, especially in the field of aerodynamics and hydrodynamics, which became well-known abroad and actually continued the pioneering studies of Euler. Many Russian scientists and engineers published interesting works on the theory of elasticity and the resistance of materials and thus made a valuable contribution to the further development of these disciplines.

At last, medicine as an applied scientific discipline has traditionally been an area of important achievements in this country. To begin with, E I Parrot did a lot to popularize the thermometer as a clinical tool for measuring body temperature. The aforementioned works of N I Pirogov, I M Sechenov, and I P Pavlov greatly contributed to the progress in practical medicine. S P Botkin in St. Petersburg and U A Zakhar'in, V F Snegirev, N I Filatov, and N V Sklifasovskiĭ in Moscow founded strong clinical schools renowned for establishing the firm scientific basis by which they checked their findings obtained by increasingly precise methods.

It can be readily seen from the above discussion that Russian science in its initial period was not independent. It chiefly began by gaining ground on account of benefits received from scientific developments in Europe, and the first scientists in Russia were one and all foreigners. The situation has strikingly changed to the opposite over the last decades. The recent progress of Russian science has occurred along new lines and advanced it in many ways ahead of European and American science on which it now has a marked influence. Many prominent Russian scientists have held professorships at foreign universities or headed research laboratories in different countries. Suffice it to mention the famous mathematician S V Kovalevskaya and the biologist I I Mechnikov considered to be the leader of the French school of immunology.

This brief historical review of scientific developments in Russia is restricted to the pre-war and pre-revolutionary period. In the present, post-revolutionary time, a large number of important studies have been completed, but their true worth is still difficult to know for the lack of historical perspective. These recent discoveries having been made by our contemporaries, we should by necessity forbear to comment on their value for fear of being personal. Therefore, they are not presented here.

To summarize this account of the development of basic and applied sciences in Russia over the last 200 years, it should be emphasized that the outstanding results obtained by Russian scientists have put them on an equal footing with their European and American colleagues and brought world fame to their country. Evidently, the Russian people have not until recently appreciated the full meaning of science. In the past, science and technology were transferred to this country from abroad like seedlings transplanted to a greenhouse, but nobody here thought about the application of scientific knowledge to the practical aims of human life. This accounts for the very small number of scientists in old Russia. It is quite obvious, however, that the economic progress of any country and successful development of its productive forces depend on technological potential. It is equally clear that technology can not develop effectively unless it is supported by progress in science. Both in Europe and in America, they are beginning to understand that science and technology must develop on parallel lines, with the former always getting ahead of the latter and governing the practical application of innovative techniques. If we wish to see technology growing more sophisticated in the third century of science in Russia, we must maintain by all possible means strong and continuing links between them, ensure rapid application of scientific achievements to practical problems, and create favourable conditions for the further development of science. Only then can we hope to compare favourably with our great predecessors and make this country technologically advanced and economically prosperous.