92.530

# LOMONOSOV AND WORLD SCIENCE*

P. L. KAPITZA

Usp. Fiz. Nauk 87, 155-168 (September, 1965)

IT is a pleasure to speak of Lomonosov, as it is a pleasure to commune with one of the original geniuses in the history of human culture. It is difficult to speak now of Lomonosov, since we are all well acquainted from grade school with his image and his works. Here it is hard to say anything new, since the life and works of Lomonosov have already been studied and discussed on all sides for 200 years. Our greatest writers, publicists, scientists, and statesmen have spoken and written about Lomonosov: Radishchev, Pushkin, Belinskiĭ, Dobrolyubov, Chernyshevskiĭ, Herzen, Pisarev, Aksakov, Menshutkin, Plekhanov, Walden, Vavilov, Fersman, Komarov, and many, many others. While some aspects of Lomonosov's work have been criticized, still, all without exception have spoken of him with great reverence, and have acknowledged his colossal influence on the development of our national culture: language, literature, education, technology, and science. The great progressive significance of Lomonosov was recognized both in the prerevolutionary times and now. Even in the last century, without fail they solemnly celebrated the festival dates of his birth and death. In our time, these celebrations are coming to have an ever larger, international scope.

The first monument to Lomonosov was erected at his birthplace in Archangel; it was made by our very great sculptor Martos. The subscription was begun in 1825, and the monument was unveiled in four years.

In 1865 (the centennial of Lomonosov's death), the Academy of Sciences instituted a yearly prize of 1000 rubles in his name. This prize was awarded alternately in the humanities and in the natural sciences. In our time the Academy of Sciences has also instituted a prize and medal in Lomonosov's name.

The only thing left undone for 200 years was the publication of M. V. Lomonosov's complete collected works. This has been carried out in the last few years.

Few of our scientists or statesmen furnish such a rich biographic and historiographic material as Lomonosov. When one becomes acquainted with this material, one cannot but regret that no good portrait of Lomonosov has come down to us. The portraits and engravings that are usually reproduced were done posthumously, and are copies of one particular original painted by an unknown and untalented artist. Only the bust done by Shubin, who personally knew Lomonosov, gives us his living and spirited image.

In studying the material on Lomonosov, one is most deeply disappointed by the fact that none of our great writers have ever drawn a picture of him as a person. Of course, even among major scientists there are many in the world whose interests are bounded by the walls of their laboratories. Usually the picture of such scientists as persons is not very interesting. However, when the work of a major scientist and great original personage such as Lomonosov encompasses the development of the culture of an entire country, and moreover, in one of the most interesting moments of its history, a living picture of him becomes of great general human interest.

The greater the man, the more contradictions he has in himself, and the more contradictions in the problems that life puts in his way. The scope of the contradictions is a measure of the genius of a man. Both the contradictions in Lomonosov's own character and those under which he lived were exceedingly great.

It is hard to find a greater contradiction than in the fate of the "peasant from Archangel," who lived and worked among the top ranks of the official and noble classes of the court. Lomonosov was a progressive statesman, he saw the necessity of public education and science, and combatted superstition and prejudice, but in order to carry out his work, he had to rely on the high noblemen of the court. In spite of his peasant origin, he understood the necessity of flattery and praise of the ruling potentates, and handled this problem in his own way. With the brilliance of his personal qualities, he gained the friendship and protection of the most influential noblemen of that time, Shuvalov, Vorontsov, and Orlov.

When Peter "opened a window" into Europe, the wind blew in more to us from the West than culture and science. Along with the true scientists such as Euler and Bernoulli, who brought us the most advanced Western science, the wind brought us a large number of foreign scientists who were mediocrities or even adventurers. The latter were interested only in material benefits and in keeping their privileged position in Russia, which gave them the opportunity to enrich themselves with ease. Naturally, they hindered the growth of Russian influence in the Academy of Sciences. It is well known how Lomonosov, while relying on the authority of the foreign scientists, had to combat the predominance of the foreigners. With

*On the occasion of the 200th anniversary of the death of M. V. Lomonosov, we are printing the text of P. L. Kapitza's speech presented on Nov. 17, 1961 at the general meeting of the Division of Physico-Mathematical Sciences of the USSR Academy of Sciences, devoted to the 250th anniversary of the birth of M. V. Lomonosov.

his acute mind, Lomonosov made an excellent estimate of the complexity of the conditions under which he worked. It demanded great endurance and tact on his part, but this was counter to his irrepressible temperament and impassioned character. Here arose the sharp conflicts well known from Lomonosov's biography. In the final consequence, Lomonosov's genius was still able to win this complex battle, but no one has yet drawn a good picture of this complex battle.

Lomonosov understood the great value of the development of science in Russia and the necessity of improving higher education. He put much work into founding the university in Moscow. He attracted the youth into scientific work, but could not himself devote as much time to scientific work as he would have liked. Apparently he was not a teacher by nature. His extreme individualism did not make a disciplined teacher of him. Consequently it happened that, while he had put so much of his effort into disseminating science in Russia, nevertheless he left no students after him. Menshutkin, the greatest expert on Lomonosov's scientific work, says that "he founded no school, and among his students after his death, the only one going into science was S. Ya. Rumovskiĭ," who was later professor of astronomy of the Academy of Sciences.

We could prolong the list of contradictions in Lomonosov's life, but to draw a living image of Lomonosov, who combined all these contradictions within himself, is a problem awaiting a major writer.

Now I would like to spend some time on one of the contradictions in Lomonosov's life. Although it is well known, it hasn't yet been properly explained. I think that it is important to us even now.

Many times Lomonosov said that his work as a poet and writer, as reformer of the Russian language, historian, statesman, geologist, or administrator was of little satisfaction to him, and that he saw his main calling in scientific work in physics and chemistry. It would seem that scientific work in chemistry and physics must have been his major activity, since he occupied the position of adjunct in physics from the very beginning of his membership in the Academy of Sciences in 1741, and he was appointed professor of chemistry within four years. One might naturally assume that under these conditions Lomonosov's genius must have left a very strong imprint, both in our national and in world science. However, we know that this did not happen, and repeatedly this has puzzled many who have studied the history of science. In a speech given before the Academy of Sciences at the Lomonosov festival in 1911, Academician P. I. Walden took up this problem in detail, and pointed out the "tragedy in the fate of Lomonosov's scientific works, which left no visible traces in chemistry and physics." Walden gave a series of data confirming the ignorance of foreign historians on Lomonosov's scientific work.

One does not find Lomonosov's name at all in Heller's (1889) or in Rosenberger's (1882-1890) detailed history of physics. The French historian of chemistry F. Hoefer (1860) wrote only a few lines about him, which are not devoid of curiosity. I repeat them verbatim: "Parmi les chimistes russes qui se sont fait connaître comme chimistes, nous citerons Michel Lomonosow, qu'il ne faut pas confondre avec le poète de ce nom."

("Among the Russian chemists who have become known as chemists, we mention Mikhail Lomonosov, who mustn't be confused with the poet of this name.")

However, while in the West Lomonosov's scientific work as a physicist and chemist was hardly known, even among us it remained either unknown or forgotten until very recently. Among all the extensive material dealing with Lomonosov up to the beginning of this century, there are only two festival articles on Lomonosov as a physicist, both printed in 1865. One is by N. A. Lyubimov, giving an untalented rehash of several of Lomonosov's works. The other, consisting of only five pages, is by N. P. Beketov. In both of the great Russian encyclopedias, both Brockhaus and Granat, just as in the Encyclopedia Britannica and in the French Larousse, they say nothing about Lomonosov's achievements as a physicist and chemist. Up to the appearance of Menshutkin's studies, there was not a single reference to Lomonosov, even in our basic physics text by O. D. Khvol'son with its meticulous citation of the literature.

On the other hand, in discussing Lomonosov's work, A. S. Pushkin said in his notes Puteshestvie iz Moskvy v Peterburg (Journey from Moscow to St. Petersburg) (1834): "Lomonosov himself didn't value his poetry, and concerned himself much more with his chemical experiments than odes on a high official Saint's day." Pushkin spoke of Lomonosov as a great man of science; his striking words made history: "He himself, rather, was our first university." Pushkin saw Lomonosov's genius as a scientist. Pushkin's opinion is very important to us as that of one of the persons most educated and deeply understanding of Russian life. Besides, Pushkin could still meet people who had seen and heard Lomonosov alive. Thus, even his contemporaries recognized Lomonosov to be a great scientist. However, it is characteristic that none of them surrounding him could describe exactly what Lomonosov did in science, beyond the fact that one had to consider him a great scientist.

Thus it continued until the beginning of our century, when the professor of physical chemistry Boris Nikolaevich Menshutkin began as a scientist to study Lomonosov's original scientific works in chemistry and physics. Menshutkin translated Lomonosov's works from the Latin and German, and critically studied not only Lomonosov's major works, but also his correspondence and personal notes. Beginning in 1904, Menshutkin systematically published this material. Later this work was continued by S. I. Vavilov, T. P. Kravets, and a number of other scientists. Thus we found out only after 200 years on what and how Lomonosov worked. Now, through knowing the path along which science has developed since Lomonosov, we can correctly evaluate his scientific work in chemistry and physics. Thus, only now has it been ascertained that Lomonosov's scientific work was most advanced for his time, and undoubtedly should have left a deep imprint in the development of world science. The intuitive estimate that Pushkin made more than a hundred years ago that Lomonosov was a great scientist was correct. All this makes us wonder more than ever: how could it happen that all this scientific work of Lomonosov took place without leaving any trace, not only abroad, but in our country? I must speak of this with sorrow, since both our science and world science suffered a considerable loss thereby. Of course, such an isolation of Lomonosov's scientific work from world science could not have happened by chance, but had its historic causes. I think that we have had many such cases in which the discoveries and achievements of Russian scientists did not exert a due influence on the development of world science. Hence, the contradictions between Lomonosov's very great achievements in science and the lack of a due influence on the development of world science are of interest even today. I shall take up this problem in further detail.

In order to analyze the relation between Lomonosov's work as a scientist and the science of his period, I must draw a picture, though in very general outline, of the conditions under which the natural sciences were developing in the first half of the 18th Century. I might mention that in the history of human culture, only the 16th Century can be considered to begin the intensive growth of the natural sciences. Before that time, mankind also knew of great scientists, for instance Pythagoras, Archimedes, and Avicenna, but they were solitary creative geniuses. Science developed slowly then. Only since the 16th Century has science begun to grow at an increasing rate, because scientific work became a collective creation of men carried out on an international scale. The first great advances in this collective creation by scientists are well known: they were the rapid growth of astronomy and mechanics. The participants were the pole Copernicus, the dane Tycho Brahe, the german Kepler, the italian Galileo, the englishman Newton, the frenchman Descartes, the dutchman Huygens, and many, many other less-known scientists.

Also today, the collective labor of scientists on an international scale is a fundamental factor ensuring the rapid growth of science. It has been made possible not only by the growth in the material welfare of people and the development of means of communication between countries, but mainly, by the invention of printing in the 15th Century. All scientists know well that even today without books one can neither publish nor preserve scientific experience and scientific advances, Without this, of course, science cannot fully develop. At the same time, science became separated from the church, as was necessary for science to develop on a sound materialistic basis.

Since that time, the leading statesmen began to understand the importance of the development of the natural sciences for the growth of human culture. As early as the beginning of the 17th Century, Francis Bacon clearly formulated the vast importance of the experimental study of nature and the inductive method of generalizing these experiments, leading to a knowledge of the laws of nature. Bacon, an important statesman who attained the post of Lord Chancellor, was convicted of bribery in 1621. He spent the end of his life in semi-exile, where he wrote the philosophical works that immortalized his name. Thus, dishonor during his life turned to glory after his death. In Bacon's writings, in an unfinished work that he called the New Atlantis, he revived anew the story of Plato's Atlantis. This island lives and is guided by scientists. We can find in the description of the island both scientific institutes and other aspects of the organization of scientific life recalling our own governmental organization of science.

Bacon gave the meaning of science as a powerful force directing the growth of the country's culture along the right path in the following beautiful image, in which science is contrasted with empiricism: "A limping cripple traveling along the right road can outrun a racehorse if the latter takes the wrong path. Furthermore, the faster the racer runs, once he has lost the way, the farther the cripple will leave him behind." Also Bacon proclaimed physics as the "mother of all sciences," which first points out the path of development of human culture. I am giving this description in so much detail because Bacon was widely read in those times, and his New Atlantis was put out in many editions. His views were propagated in the ruling circles of the advanced countries, and at this time the development of science began to be considered to be a governmental concern. At the same time, scientific work had expanded so much that the need arose of coordinated work. Therefore, as early as the 17th Century, they began to establish academies of science in many countries, or analogous scientific societies. Periodical scientific journals and memoirs began to be printed.

When Peter I visited Europe, he quickly grasped the significance of science in the development of a country, and of course, he could not but understand that Russia also needed science in order to become an advanced, cultured country. Here occurred the famous conversations of Peter with Leibnitz on this subject, and the idea arose of founding an Academy of Sciences in Russia. Our Academy was established in 1725 in the reign of Catherine I, already after the death of Peter. As is well known, the Academy was made up of foreigners in order that they should train Russian scientists. We know that Lomonosov was fortunate—he arrived in St. Petersburg at the right time to become one of the first Russian students in the Academy of Sciences. Of course, however, the Academy of Sciences was even more fortunate in that their first Russian student was Lomonosov. He got his higher scientific training in Germany, where he studied for five years, mainly under Professor Christian Wolff. In 1741, Lomonosov returned to St. Petersburg, where he had to begin his scientific work under very unfavorable conditions.

Around that time, the Academy of Sciences already had existed for almost twenty years, Anna was reigning, Biron ruled, and Peter's idea of the development of Russia's own science began to take second place. When the Academy of Sciences was founded among invited foreigners, there were only two real major scientists, both of whom had become famous. They were Leonard Euler and Daniel Bernoulli. However, attention to them had continued to decline, and in 1741, when Lomonosov returned from Germany to St. Petersburg, both of them had already left the Academy, first Bernoulli and then Euler. Interestingly, Euler had left St. Petersburg three days before Lomonosov returned from Germany, and returned to St. Petersburg only in the reign of Catherine II, when attention to scientists had begun to increase again. However, this was a year after Lomonosov's death. Thus, while Lomonosov corresponded much with Euler, they never met personally, if we do not count Lomonosov's possible attendance at Euler's lectures before he left for Germany.

Thus, in the Academy of Sciences in the field of his studies in physics and chemistry, Lomonosov was left in almost complete isolation. He had to follow the development of science in the literature, which was scanty then. He had no personal contact with important scientists, since from the time Lomonosov became a scientist, he never went abroad, while foreign scientists never came to St. Petersburg to confer with him, for the Academy of Sciences of that time was of no interest.

In spite of this isolation from world science, Lomonosov was still able to concentrate his studies in the most pressing problems of chemistry and physics of that time. As a scientist, he combined the thinker and the experimenter within himself. His remarks on the relation between theory and experiment are of interest, and are quite to the point even today: "some theoreticians, who without any preliminary experiments, abuse their leisure to dream up an empty and false theory and burden the literature with it...".

Lomonosov put experiment in first place in the study of nature. This was his characteristic trait as a scientist. Therefore he put much effort into establishing a laboratory, and worked there assiduously. However, the milieu of that time valued Lomonosov little as a scientist, but most of all as a poet. For one of his eulogistic odes, Lomonosov received 2000 rubles from the Czarina. This was more than his salary for three years in the Academy of Sciences (660 rubles per year).

They also valued Lomonosov as a historian, as the founder of the literary Russian language, for his grammar, for his translations, and they valued him as a statesman concerned with the development of education and technology in Russia.

The meaning of his scientific enterprises in the laboratory was incomprehensible to the officials and the court. In order to justify his laboratory enterprises, Lomonosov wrote in 1753 to Count Shuvalov: "I suppose that I might be permitted to spend several hours a day on physical and chemical experiments instead of billiards...". Thus, Lomonosov had to justify his scientific work in that he spent leisure time on it instead of games and billiards. Of course, the justification of the expense of government funds on the laboratory were the practical results, for instance, the production of mosaic glass and the solution of various technical problems.

It is amazing how much Lomonosov did in the field of experimental basic science, in spite of these unfavorable conditions. First, he very widely covered various fields of physics in his studies. He studied the liquid, solid, and gaseous states of substances. He meticulously developed thermometry, and precisely calibrated his own mercury thermometers. Using them, for example, he determined the expansion coefficient of gases upon heating with a remarkable accuracy for his time. If we compare his data with the modern values, we find that he made an error less than 3%, which was 10 times more precise than the value accepted then. This shows Lomonosov's extremely good technique as an experimenter. It would take too much time to enumerate the rest of Lomonosov's achievements in the field of experimental physics and chemistry, which were performed on the same high level, and this is not our topic. Those interested in this problem can read B. N. Menshutkin's excellent monograph on Lomonosov's work in physics and chemistry, which was published in 1947.

Undoubtedly, these studies by Lomonosov must even in themselves establish him in the ranks of the most important experimentalists of that time. Interestingly, Lomonosov's electrical experiments, in which he developed further Franklin's work, are better known, not for their scientific results, but from the fact that they resulted in the death of Richmann, who was killed by a lightning discharge. These studies led Lomonosov to propose an interesting hypothesis on the nature of the electric discharge in clouds.

He also had a series of optical studies, which amounted to constructing more refined optical instruments, e. g., a reflector telescope, with which Lomonosov observed a rare phenomenon in 1761, the transit of Venus across the Sun's disk. These observations were also a major contribution to science. He observed the deformation and blurring of the edges of the disk of Venus. Thus he was the first to show that Venus must have an atmosphere. It is interesting to note that modern astronomical textbooks say that such a demonstration was made only in 1882, i.e., 121 years later, when Venus again transited the Sun's disk.

Lomonosov's most important achievement was the experimental proof of the "law of conservation of matter." Lomonosov's discovery of the law of conservation of matter is now well studied, and it has been thoroughly established beyond a doubt that Lomonosov was the first to discover it. In 1756 he performed a classical experiment, in which he showed that lead plates are oxidized upon heating in a sealed vessel, but without change in the total weight of the vessel. Lomonosov's experiment was analogous to Lavoisier's famous experiment, but Lavoisier's came 17 years later. I shall not repeat in detail this entire story, for most of you know it all. Undoubtedly, this discovery of one of the most fundamental laws of nature should have established the name of Lomonosov in the history of science among the greatest world scientists.

However, all of these studies of Lomonosov were not only poorly known abroad, but most of them were not known to us until the cited studies of Menshutkin. Evidently, under these conditions, Lomonosov's work in physics and chemistry could not exert its due influence on the growth of either world science, or our own.

Why did this happen?

It would seem that the first reason why Lomonosov's work was poorly known abroad might be that he put no stock in the priority of his discoveries, and did not publish enough. People put no less stock in priority in scientific work then than now. It suffices to recall the dispute on the priority of discovery of the differential calculus between Newton and Leibnitz, which turned into a major diplomatic incident. Here Leibnitz's career suffered greatly.

The material that has come down to us shows that Lomonosov too put stock in priority, and hence published his studies either in Latin or in German. He had an excellent command of both languages. An indication that Lomonosov was concerned that his scientific work should be known abroad is the following. In 1753, when Richmann was killed by lightning, the general meeting of the Academy of Sciences was adjourned, but Lomonosov asked for an opportunity to give his lecture on electricity, "before it lost its novelty." Therefore, the president of the Academy of Sciences, Count Razumovskiĭ, ordered a bill passed on the coronation festival: "that Mr. Lomonosov's new works should not be late in reaching the scientists of Europe, and thereby that his work should not be missing among the electrical experiments performed up to now." Lomonosov's lecture was sent out thereafter to many foreign scientists. It is also known that Lomonosov wrote about his experiments to Euler and a number of other scientists. We should note that in those days they considered personal correspondence between scientists to be one of the most effective methods of spreading scientific information, and used it widely. Thus, there are no grounds to think that scientists couldn't have known of Lomonosov's work, either here or abroad. They knew of them, but didn't pay due attention.

Some of Lomonosov's biographers have advanced the hypothesis that the lack of attention to Lomonosov's studies arose from the fact that his ideas were extremely advanced. I think that this hypothesis is also ungrounded. Actually, Lomonosov's lively and bold mind encompassed almost all fields of natural science found in the circle of interests of the "natural philosophers" of that time. In breadth of grasp, it is hard to name another scientist contemporary to Lomonosov with such varied interests and knowledge. Lomonosov's theoretical ideas in the fields of science immediately where he conducted his experimental work (the study of heat, the states of matter, and chemistry) impress one with coinciding even in detail with the pathway along which these fields developed after Lomonosov, and are developing even today. The fact that the kinetic nature of heat was quite evident to Lomonosov is very striking to the modern reader. He graphically associated the heating of a body with an increase in the translational and circular (rotational) motion of atoms and molecules, which of course he called by other names. The false notion of the existence of "caloric" prevailed in physics then. While these views of Lomonosov were advanced, he wasn't their lone proponent, since, e.g., Bernoulli also shared them. Lomonosov developed these views extremely systematically and logically. For example, he came very close to the concept of the absolute zero. In the discussion "on heat and cold" in Sec. 26, he speaks of the "highest possible degree of cold, involving complete rest of the particles and cessation of any motion in them."

The following curious fact may serve to illustrate Lomonosov's conviction of the correctness of his conception of the physical nature of heat. In 1761, Lomonosov wrote the note, "On the Multiplication and Preservation of the Russian People." In this note he discussed the various cases for the high mortality in Russia, and proposed a series of measures for combatting it. Thus, in Sec. 7 he writes that children should always be baptized in warm water: "the priests carry out the prescriptions of the Prayer Book that the water should be natural without adulteration, and take heat to be an added material, without thinking that in summer they themselves perform baptism in warm water, which in their opinion is adulterated, and are thus contradicting themselves; and especially, in their thoughtlessness, they do not know that even the coldest water still contains very much heat. However, there is no need to explain physics to the ignorant priests."

Interestingly, this note was never published in Tsarist times, since the thoughts expressed in it were extremely revolutionary.

Lomonosov's ideas guiding his studies in the field of chemistry were also perfectly correct and advanced. He always based himself on atomic concepts, and approached the idea of the molecular structure of chemical compounds. He considered it necessary to use the quantitative method in scientific studies in chemistry. He developed precise methods of weighing. He considered it important to use as pure reagents as possible. This is the quantitative approach to studying chemical reactions that led him to the necessity of proving experimentally the law of conservation of matter. All this gives us complete reason to consider Lomonosov to be the founder of the introduction of physical research methods into chemistry in the sense that it existed in the 18th Century.

Lomonosov did less in the field of electricity. He knew of the experiments of his contemporary Franklin, and he repeated them, but Lomonosov directed his major interest to problems concerning atmospheric electricity. He related its origin to the rising and falling air currents that always accompany thunderclouds. This opinion is considered correct even today, but the very mechanism of origin of the charge of a cloud proves to be so poorly amenable to research that it hasn't been settled finally even now.

In the field of wave optics, Lomonosov, along with Euler, correctly supported the wave theory of light proposed by Huygens, whereas the authority of Newton, who stubbornly insisted on his erroneous corpuscular theory of light stood in the way of its acceptance. However, Lomonosov fell into error in the further development of the theory of light. The same happened to Euler.

Lomonosov's most important error in one of the fundamental problems of physics is of great interest.

As we know, Galileo discovered one of the most remarkable laws of nature. He established that the mass of a body, independently of its nature, is proportional to the force of gravity, or simply to its weight at a given point in space. Newton showed that this law is obeyed very exactly. Newton's experiment is very simple, precise, and convincing. In a doorway in his room at the college he hung two pendulums of the same length, but made of different materials. It turned out that the pendulums always oscillated in strict synchronism, regardless of the materials suspended. This could happen only if the mass of a body is strictly proportional to its weight. Lomonosov thought that this was wrong. He began to make remarks on this topic in 1748, and continued until 1757. All of these statements were made at a time considerably later than Newton's pendulum experiments. However, all this time Lomonosov amazingly stubbornly opposed this law. Thus, in 1755 Lomonosov proposed that the Academy of Sciences offer as a prize problem the experimental testing of the "hypothesis that the matter in a body is proportional to its weight." The posing of this problem met objections in the Academy of Sciences as contradicting the views of the great Newton, and Euler was brought in as the arbiter. Euler, who was usually on Lomonosov's side, did not support him in this case, and opposed the posing of this problem. We should note that Lomonosov's only student, S. Ya. Rumovskiĭ, also didn't share Lomonosov's views, as we see from his letters to Euler in 1757. Rumovskiĭ, who later became an academician, studied mathematics two years with Euler in Berlin, and of course, knew Newton's mechanics well. Perhaps, Rumovskiĭ was then able to show Lomonosov his error, since after 1757 I have found no sign of Lomonosov's having raised this problem anew.

Nothing is so instructive as the error of a genius. It seems to me that in this case the error didn't happen by chance, but had a deeper reason. It would take far more time than I have to discuss this topic with confidence.

I assume that the reason for Lomonosov's error involves a philosophical concept to which he erroneously decided to grant universal meaning. This concept of Lomonosov's consists in the idea that motion is always conserved in nature, is never created nor destroyed, but is only transmitted from one body to another, and only by direct contact. We know that this idea is correct in the case of elastic collision of spheres. Now we also know well that if we consider the collisions between atoms and molecules as collisions between elastic spheres, we can construct a complete and correct picture of the kinetic nature of heat. Thus we can understand why Lomonosov, who on the one hand accepted the atomic structure of matter, on the other hand treated the interaction between atoms as subject to the laws of collision of elastic bodies. Thus he was the first to be able to construct correctly an almost complete picture of thermal phenomena based on kinetic concepts. As I have said, he not only came close to defining the absolute zero, but also came very close to formulating the law of conservation of energy, of course not in a general form, but only for the transformation of kinetic into thermal energy.

Lomonosov's error lay in the fact that he ascribed a universal character to his idea, and began to think that only one means of interaction between bodies exists in nature, and this was through contact. Lomonosov rejected the possibility of action at a distance by gravitation or electric interaction. In developing these ideas, he thought that when a body has gained velocity under the action of gravity, then it is necessary that the medium surrounding the body should lose velocity. The medium having such a property of generating motion was of course hypothetical, and Lomonosov postulated its existence in nature. He tried also to describe electric interaction between bodies analogously. It is not hard to understand that on the basis of these ideas Lomonosov not only could not draw a clear picture of phenomena involving interaction of bodies at a distance, but they led him to deny the existence of a universal relation between the weight and mass of bodies.

It is hard to understand how Lomonosov, in developing these views, could fail to treat the described pendulum experiments of Newton. Perhaps he either didn't know of them, or didn't understand them, for I haven't been able to find anywhere any mention by Lomonosov of these experiments. When one becomes acquainted with Wolff's textbook of physics, which Lomonosov studied and translated into Russian, it strikes one that due attention is not paid to Newton's work in mechanics. There is also no mention of the described pendulum experiment. Interestingly, the only problem of mechanics that Wolff devotes attention to is precisely the collision of spheres. I have compared the writings of Christian Wolff with those of other physicists of that time; he impresses me as a scientist with limited powers in physics. He owed his fame, as we know, to works on abstract philosophical topics. Apparently, Wolff did not inoculate Lomonosov with the elements of concrete mathematical thinking, without which it is hard to grasp Newton's mechanics. As I have pointed out, Lomonosov had no opportunity to meet such scientists as Bernoulli and Euler, who not only had an excellent knowledge of Newton's mechanics, but also were themselves famous for developing it for a continuous medium. I can say with assurance that if such a communication had existed, Lomonosov would not have made this error.

The saddest thing in Lomonosov's fate was that he could spend only a small fraction of his energy and time on his experimental studies. With all his great erudition and exceptional imagination, he had no opportunity to subject all his hypotheses to experimental test. Thus it happened that in the fields in which Lomonosov worked experimentally, his theoretical and philosophical concepts were on the right track. But wherever he was divorced from practice and tried to gain the truth deductively, he often lost the right track. If he had been established in circumstances where he could have developed his experimental work more extensively, e.g., if he had had many students, then certainly he would have made far fewer false hypotheses. With his exceptional imagination, Lomonosov could have been the director of a large scientific school. However, the conditions for founding such a school did not exist in Russia at that time.

Thus, the explanation that Lomonosov was not recognized as a scientist because he was divorced far from reality is ungrounded.

It is à propos here to recall that generally in the history of Russian science, the Russian scientists were often isolated from world science. I think that we should seek a general cause that is more profound than those mentioned. However, before going on to discuss it, I consider it useful to mention briefly another unrecognized Russian discovery highly reminiscent of Lomonosov's case.

A very major discovery in physics was made in our country at the very beginning of the 19th Century, which also did not have its due influence on world science. This happened in 1802, when Vasiliĭ Vladimirovich Petrov discovered the phenomenon of the electric arc discharge in a gas, which he called the "voltaic arc." Now we all know well the entire subsequent vast role of the arc discharge, both in science and in technology. However, now in our time it is hard to judge by their merits all the difficulties of the discovery of this fundamental phenomenon, as was done first by Petrov. It was done eleven years after the discovery of the galvanic current, and only three years after Volta had invented the galvanic pile. Of course, little was known about the galvanic current within these three years. Petrov himself not only had to make batteries consisting of 4200 copper and zinc disks stacked in a pile more than three meters long, but also he himself had to make the wire, insulating it with sealing wax.

Petrov observed the arc discharge not only at normal pressure, but at reduced pressures, by passing the current through an evacuated bell jar. We can now consider his discovery of this type of discharge to be the discovery of a plasma. Although Petrov's studies were published in individual pamphlets and sent out to many of the scientific establishments of that time, still the discovery of the arc discharge is usually credited to Davy, although he did it only in 1810. Petrov performed a number of other interesting studies in luminescence and chemistry. Apparently he was the first to decompose water by electrolysis, but none of these studies exerted their due influence on world science.

Petrov's biography is very instructive. The son of a parish priest, he began his work as a humble teacher in Bernaul in a provincial school, and later gained the position of professor of physics in the Medico-surgical Academy in St. Petersburg. Like Lomonosov, Petrov was a solitary scientist, and he also left no school after him. His studies and he himself remained unnoted in the history of science, not only abroad but also here. No portrait of Petrov has been preserved, and it was only recently found where he is buried. I have no doubt that for his scientific discoveries, Vasiliĭ Vladimirovich Petrov should have occupied one of the most prominent places as a major experimental physicist, not only in our science, but in world science.

One often has occasion to hear that the inattention to the achievements of Russian scientists is to be explained by the fact that in the West they usually considered the culture of the Slavs to be second-rate, and not worth considering in the history of world culture. Undoubtedly, in the 18th and 19th Centuries they quite often had this attitude to the Slavs in general, and the Russians in particular. However, I do not think that it can explain the question at hand, since the history of science shows that the evaluation of the scientific attainments of major scientists has always extended beyond national boundaries. They recognized Copernicus, even though he was a Slav. It suffices also to recall that Euler repeatedly spoke highly of Lomonosov's work. Besides, this doesn't explain why we ourselves had so underestimated the scientific work of Lomonosov, Petrov, and a number of other Russian scientists.

I think that we must seek the explanation in the conditions under which science was developing in the country. It is not enough for a scientist to make a scientific discovery for it to influence the development of world culture. It is necessary that certain conditions should exist in the country, along with a necessary connection with the scientific community abroad. If these conditions do not hold, then even such remarkable scientific studies as those of Lomonosov and Petrov cannot affect the development of world culture.

It is these conditions, which were necessary in Lomonosov's time just as they are important today, that I want to take up now.

As I have said, since the 17th Century the natural sciences have begun to grow considerably faster than before, owing to the collaboration of scientists on an international scale. This could happen only because these sciences, when developed on an experimental basis, are the same for all mankind. This characteristic of unity of materialistic science has made possible its development in a broad international community of scientists. The pattern that the international collaboration of scientists follows is well known, and remains the same today as in the time of Lomonosov. The different countries have their own groups of scientific workers, who are found in universities, academies, and other scientific institutes. Since each scientific field or problem can grow only in one direction lest it lose this true direction, it is necessary to move slowly and spend much effort in exploratory work. Collaboration in scientific work consists in the fact that these laborious exploratory studies are distributed among collectives of scientists working on a given problem. The work of a scientist done outside a collective usually remains unnoted.

Life continually shows that such a collective effort of scientists can occur only through personal contact, either within a country or on an international scale. In order that a scientist's work become known, he must not only publish it, but further he has to convince people of its correctness and prove its importance. All this can be done successfully only with personal contact. Both in Lomonosov's time and today, in order that a scientist may influence the collective work with his studies, he needs personal communication, he needs a lively exchange of opinions, and discussion. None of this can be replaced by printed work or correspondence. It is not so easy to explain why this is. I think that most of us know from our own experience how necessary personal contact between people is in harmonizing creative work. Only when you see a person, see his laboratory, hear the intonation of his voice, see the expression on his face, do you trust his work and want to collaborate with him. For this very reason, no textbook can ever replace the teacher.

Today, the necessity of personal contacts between scientists is accepted as something self-evident, both by our own and by foreign scientists. They are continually increasing, and now occur on a broad scale through congresses and conferences.

In Lomonosov's time, personal encounters of scientists were already widely developed. Usually it happened as follows. A leading center of scientific work in a given field of knowledge would be founded in some country. Naturally, such a center would attract to itself other scientists, often those working alone. In the 18th Century science was strongest in England. This is explained by the wealth of the country, which was exceptional for that time. The country's patrons supported science, and it could develop most broadly. For example, Franklin went there, a man who had been a solitary scientist in America, according to Lomonosov. He gained recognition for his remarkable studies on electricity when he reported them at the Royal Society in London. Also Leeuwenhoek gained full recognition for his microscope studies after a trip to London, whereas they were first treated with doubt.

The tragedy of isolation from world science of the work of Lomonosov, Petrov, and others of our solitary scientists consisted only in the fact that they could not be included in the collective work of scientists abroad, since they had no opportunity to travel abroad. This is the answer to the question that we have asked, that of the reason for the lack of influence of their work on world science.

Now we still have to take up the question of why Lomonosov's scientific work was not recognized for so long in our own country. It is quite clear that for a scientist to be recognized, the society surrounding him must be on a level so that it can understand and evaluate his work in its essence. Of course, neither the administrative official apparatus nor the high nobles surrounding Lomonosov could understand the meaning of his scientific work, and hence, it only became possible to recognize his work in physics and chemistry when a scientific community had arisen in our country.

We should consider this lesson of history in order to evaluate the great role played by the community in the organization of science. Today this is very important to us, since we have the problem before us of building the most advanced science.

As we know well, any creative labor needs a relation to society to develop successfully. A writer, actor, musician, or artist creates at his maximum and develops his talent only when he is related to a community. The creative work of a scientist also cannot develop successfully outside a collective. Furthermore, just as the level of art in a country is determined by the tastes and culture of society, the level of science is determined by the degree of development of the scientific community. The tragedy of Lomonosov was redoubled by the fact, as I have said, that our country did not have a scientific community at that time. The lack of a sound critical collective hindered Lomonosov from being able to see where he was going on the right track in his investigations, and where he was in error.

Hence, Lomonosov could not manifest the full power of his genius. He painfully experienced the lack of understanding and recognition of his work in his own country as well as abroad. He did not gain the full satisfaction in his creative work that he deserved by virtue of his genius.

It is not hard to see that an advanced scientific community must exist for the development of an advanced science. If we had not created our own advanced scientific community, then we could not have built an advanced science in our country, no matter how many Lomonosovs were born among us. The creation of a sound, advanced scientific community is a major problem that we still pay insufficient attention to. This is more difficult than the training of selected talented youth for scientific work or the building of large institutes. The creation of a sound community includes the education of broad strata of people involved in scientific work. They must be trained to be interested broadly in science, to esteem and love their science, to be able to evaluate objectively the advances of our science, and to support all that is actually important and best in science. It is only a scientific community able to evaluate a scientific advance correctly that can help the scientist follow the right track.

Only an advanced scientific community can evaluate the cognitive power of a scientific advance independently of its immediate practical significance.

All the natural sciences can develop in the right direction only by relying on a sound scientific community. As I have noted, we discovered and recognized Lomonosov at the beginning of this century, not by chance, but only because a sound scientific community had begun to grow among us at about that time. The community in physics developed in our country when the material conditions for scientific work had improved, and it became possible for our major scientists of that time, Lebedev, Rozhdestvenskiĭ, Lazarev, and Ioffe, to found their schools.

Now under socialism, when science has been made the basis of development of society, the influence and significance of our scientific community is growing rapidly. We must remember that in order that our science may be the most advanced, our scientific community must also be the most advanced. It must be leading and authoritative, so that its judgments and evaluations will be recognized on a world scale.

Translated by M. V. King