LOMONOSOV AND HIS CONTRIBUTION TO NATURAL SCIENCE

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INTRODUCTORY. *A French historian tells us that Lomonosov the poet, should not be confused with Lomonosov the scientist. This is hardly a true statement of fact, for in reality there was only one Lomonosov. He was not only an outstanding poet whose influence on the Russian language was quite as important in its way as the revolution brought about by Pushkin, a grammarian whose work survived almost a hundred years,—but also a scientist with remarkable powers of observation and unusual mathematical insight.*

Lomonosov, a contemporary of Benjamin Franklin and a forerunner of Lavoisier, was the first Russian chemist. Indeed, he may be called the founder of our modern physical chemistry.

A brief exposition of his life and his contribution to natural science will be found in the following pages.

MIKHAYLO VASILEVICH LOMONOSOV was born about the year 1711[1] in the village of Denisovka, which lies on a small island in the river North Dvina, opposite the town of Kholmogory. This town was historically important and was probably founded before the XVth century. In its early days it served as a trading-post of Novgorod the Great. As early as the middle of the XVIth century (1553) an Englishman, Robert Chancellor, had rounded the North Cape, had come through the White Sea and found his way up the North Dvina to Kholmogory, which was the only open port of Russia. After visiting the Tzar in Moscow and obtaining permission to trade and build warehouses, Chancellor returned home. Two years later he was back again with more ships, some of them belonging to Dutch merchants. As a result of the trade which was established at that time, the town of New Kholmogory was founded at the mouth of the river. It was this town that was later renamed Archangel, and it was here that Peter the Great began his first experiments in building Russian seagoing vessels.

Vasily Dorofeech, Lomonosov's father, though of the peasant class, was a well-to-do fisherman, owning several boats and, it is said, even one that was square-rigged. He used to go down the river and far out into the White Sea on fishing trips, often taking his son, Mikhaylo, with him. At Archangel foreign ships discharged their cargoes and their crews were seen everywhere on its streets. It is probable that the Lomonosovs often stopped there to trade and to purchase supplies.

1) Dates throughout this paper are according to the Gregorian calendar used in Russia.

Lomonosov was brought up in these surroundings. His horizon was necessarily far broader than that of his contemporaries in the heart of Russia.

Early in his youth, Lomonosov acquired a strong interest in natural science. In Kholmogory the opportunities for learning were very limited, and Mikhaylo was unable to obtain any books with which to satisfy his inquisitive mind. After much trouble he found a grammar by Smotritzky, and an arithmetic by Magnitzky. The latter was not only an arithmetic, but also gave an account of physics, geometry, astronomy, geography and navigation, written in popular form. These two books he learned by heart, and later referred to them as the "gateway of his learning." He felt that in order to study further, he must know Latin, the scientific language of those days. This could not be acquired in Kholmogory.

His home life, with a step-mother, was far from happy, a fact which probably influenced his decision to leave for Moscow. The County Record bears witness to his legal departure: "On the 7th of December, 1730, Mihailo Vasiliev Lomonosov is allowed to go to Moscow and to sea, until September 1731; in payment of his poll tax, Ivan Banev pledges himself."

Upon arriving in Moscow, Lomonosov entered the Slavo-Greek-Latin Academy, which had been founded in 1684 by Byzantine scholars who taught Latin, the Slavic language, geography, history, dogma and arithmetic. He writes as follows of his early days there: "While studying in the Spasky School (the Academy) I was filled with longings which diverted my mind from science. In those days I was struggling under an overpowering pressure. On the one side, my father, having only myself as a child, was writing to me that I had abandoned him, and that the wealth which he, with great labor, had gathered for me, would be plundered by strangers after his death. On the other side there was unspeakable poverty. Having one *altyn* (3 kopeks 2) per day as salary, it was impossible to spend more than one *denejka* (½ kopek) for bread and *kvass* (a drink), the remaining must go for paper, boots and other necessities. On the one hand, I received letters from home saying that people there, knowing of my father's wealth, would gladly offer me their daughters in marriage; such offers I had had while still at home. Yet, on the other hand, the students here, all small boys, pointed and shouted at me, 'Look at the numb-skull who comes at twenty to study Latin!'"

The salary received by Lomonosov was indeed meagre, but it must be remembered that in those days a kopek was worth far more than now. A pound of meat cost less than two kopeks. In 1741 Leonard Euler, the famous mathematician, sold his rather large house in St. Petersburg for three hundred roubles,[2] and was very much pleased with the transaction.

Despite his poverty, Lomonosov was able to continue his studies, for kind friends at home sent him food, and at times, money.

What were those studies? In these days of questionnaires and psychological

2) The rouble — 100 kopeks. The pre-war value of the rouble was about 50 American cents.

tests, it is interesting to know what sort of questions were put to students two centuries ago:

"Where were the angels created?"

"Can they move themselves, and can they move other bodies?"

"How do they communicate with one another?"

"How much space is occupied by an angel?"

"Why do old men lose their hair, and why do not women grow beards?"

In the light of the above questions, it is not surprising that in 1734 Lomonosov went to the Theological Academy in Kiev, where he hoped to study more mathematics and physics. Again he was disappointed, and a year later returned to Moscow, quite undecided what to do next.

Fate was kind to him. The President of the Academy of Science, founded by Peter the Great, was looking for a chemist who also knew metallurgy and geology. He wished to send him on an expedition into Siberia to explore its natural wealth. Since such a man could not be found in Russia, it was decided to send a few able students abroad to be educated in these subjects. Fortunately for Lomonosov, he was one of those who was chosen.

In 1736 the students set off for Germany: first, to the University of Marbourg to study natural sciences under Professor Christian Wolff, and then on to Freyberg to perfect their knowledge under the guidance of Bergrat Henkel. Their stay abroad was full of semi-tragic elements. In the free atmosphere of German student life, much time was devoted to gayety, which entailed the spending and consequent borrowing of money. Upon their departure from Marbourg, Professor Wolff wrote the Academy: "While they were here, they terrorized everybody. People were afraid to say anything against them. Their departure has freed me from much trouble." In spite of these diversions, the studies at Marbourg left a profound impression on Lomonosov's mind, and it was there that he became well grounded in the fundamental sciences.

At Freyberg life was more peaceful, though money was still lacking. After paying the debts in Marbourg, the Academy was loath to send more. Not long after this, Lomonosov decided to return to Russia. On the way home he married Elizabeth Filch, the daughter of a member of the City Council of Marbourg. He left her temporarily in Germany, and after many incidents of lesser importance, finally arrived in St. Petersburg.

The ensuing period of Lomonosov's life is closely associated with the fate of the Academy of Science. The idea of an academy of science was probably suggested to Peter the Great by Leibnitz, who also drew up a plan for the dissemination of Western civilization in Russia. However, it is Christian Wolff to whom we are indebted for assistance in carrying the project to a practical end. Wolff favored the foundation of a university where Russians could be trained as scientists, rather than an Academy where Germans (the only scientists available) should be installed at once. The actual plans, which were essentially a combination of the two ideas just mentioned, were drawn up by Blumentrost. The Academy was to include a high school and university, as well as the Academy itself.

Peter the Great did not live to see his plans completed. His wife, Catherine I, officially opened the Academy in December 1725, and appointed Blumentrost its first President. However, it was Christian Wolff who chose the scientists for the Academy and their high standing may be judged by the names of some of the first members: Herman, Nicholas and Daniel Bernoulli, Bilfinger, Bayer, De l'Isle and later Euler.

It was in the summer of 1741 that Lomonosov arrived in St. Petersburg, and with the help of the all-powerful Secretary of the Academy, Schumacher, he was appointed Assistant in Physics, with a salary of 369 roubles per annum. Two years later Lomonosov's wife came from Germany, and in the year of 1745, another important event took place in his life—he was appointed Professor of Chemistry, thus becoming a Member of the Academy.

The years preceding Lomonosov's last appointment could hardly be called peaceful, either for himself or for some of the other members of the Academy.

On the 25th of November, 1741, Elizabeth (daughter of Peter the Great) ascended the throne. The reign of the all-powerful Baron, of German extraction, was ended. With his fall came the patriotic cry: "Down with the Germans." A wave of patriotism caused dissensions in the Academy.

Lomonosov took the lead in this drive against the Germans, with a rather primitive enthusiasm. In the autumn of 1742, he had a fight with Sturm, the German gardener of the Academy, in which he inflicted with his fists, a severe beating on Sturm himself, his guests, his wife, and his servants. This year and the following ones, Lomonosov spent mostly under arrest. Not long after this, an acquaintance, Goloubtzov, complains that "Lomonosov struck me with a candelabra in the face which gave me a pain in my eye and a gash on my face so that I could not appear in public."

Stories of this sort are numerous, and unquestionably illustrate Lomonosov's inability to curb his discontent without physical action. But such a lack of civilized tradition was characteristic of Russians in those days, and especially of people of Lomonosov's type, who broke away from the traditions of Holy Russia, and had not yet acquired enough of any other tradition.

Before Lomonosov, the Chair of Chemistry was held by Burger, who came to St. Petersburg in 1726. All that is known of him is that on July 22nd of the same year, going home from a visit, he fell from his carriage and was killed. The next "chemist" was a botanist, Gmelin. Soon after his appointment he went on an expedition to Siberia, where he stayed for eleven years. After his return to

St. Petersburg, he spent all of his time classifying his valuable botanical collections. It is evident that both of these "chemists" contributed nothing, either to theoretical or experimental chemistry.

Upon his appointment as Professor of Chemistry, Lomonosov realized the necessity of building a chemical laboratory. In the summer of 1746, permission was granted him, and two years later, a laboratory was erected at a cost of about $650. It contained three rooms: one with a stove and hood for manipulations involving heat, another serving both as a class and balance room; the third was used as a storage room. In this laboratory Lomonosov performed numerous experiments and here he delivered what he called a course in physical chemistry, the first course ever delivered in this science.

From this time on Lomonosov's activities were not confined to science. He compiled a Russian grammar, the first to contain a scientific and well-built theory of the language, and also wrote a history of Russia, though complaining that it took him from his chemical experiments.

Another of his activities was the making of mosaic pictures. Between the years 1749-1751, he performed more than 2,200 experiments in order to develop a method of staining glass. He was finally successful in 1753, and organized a factory for the making of mosaics. The factory produced rather unusual works of art; several of the pictures are extant at the present time.

The desire to spread education in Russia, which perhaps may be called the moving factor in all of Lomonosov's activities, led him to the idea of opening an institution of higher learning in Moscow. Though the project was executed by Count Shuvalov, Lomonosov drew the actual plans for the organization and administration of the University of Moscow (founded in 1755).

The last years of Lomonosov's life were disturbed by much administrative work, in which he had to fight the intrigues and moves of his enemies, who plotted with far greater ability than Lomonosov ever could muster. It is the very honest man who always loses in politics.

On April 4th, 1765, Lomonosov died of influenza. His body lies buried in the Alexandro-Nevsky Monastery in St. Petersburg.

Contribution to Chemistry and Physics

Soon after Lomonosov's return from abroad, he wrote the *Elements of Mathematical Chemistry*, (1741). According to him, chemistry is a "science of changes occurring in a complex body. . . The theoretical side of chemistry consists of a philosophical understanding of changes occurring in complex bodies. A true chemist must always be a philosopher. Those who busy themselves only with the practical side, are not true chemists." (1)[3]

In the same treatise we find the following definitions:

"An element is part of a body consisting of no smaller different bodies."

3) The figures in parentheses refer to bibliography at end of article.

"A corpuscle is a segregation of elements in a single small mass."

"The corpuscles are homogeneous if they are composed of the same number of the same elements bound in the same manner."

"A compound body consists of two or more different elements, so bound to each other, that in every separate corpuscle there is the same proportion of elements (of which the body consists) as in the whole compound body, among all the elements." (2).

If we replace the word corpuscle by the word molecule, the above definitions might equally well be found in any modern text-book on chemistry.

"All changes in bodies come from motion . . . motion may be explained by the laws of mechanics. . . . He who wishes to penetrate chemical truths deeply, must necessarily study mechanics. Since the knowledge of mechanics presupposes the knowledge of mathematics, he who strives to undertake an intimate study of chemistry must know mathematics thoroughly." (1).

"Many deny the possibility of basing chemistry upon the elements of mechanics and make of it an exact science. . . . If those who obscure their days with smoke and soot, and in whose brain reigns chaos from a mass of experiments which have not been thought through, would deign to learn from the divine laws of geometricians . . . unquestionably they would penetrate deeper into the mystery of nature. In practice, mathematicians derive many truths from the conjunction of a few lines: why cannot the chemist derive even greater laws from the abundance of existing experiments? I can find no reason, except their illiteracy in mathematics." (1).

"I hope you will inquire here, why up to the present time, students of natural science have made so little progress. I will answer that for this study, an able chemist and profound mathematician, all in one man, is needed. The chemist must be one who understands his science, not only from reading books, but by using his own hands diligently."

"The eyes are useless to him who cannot open a thing with his own hands. The hands are useless to him who has not eyes to see that which is within. Verily, chemistry may be called the hands and mathematics the eyes of physics." (3).

These quotations need little explanation. In addition to his philosophical statements, there is abundant evidence that Lomonosov not only preached the doctrine of physical chemistry, but also practised it. It is to him that we are indebted for a systematic use of weight and volume in physico-chemical work.

One of Lomonosov's students, Klementiev, in a dissertation presented to the Academy on the 26th of April, 1754, quotes his teacher as saying: "I think there is no scientist who does not know that there exist innumerable chemical experiments, but at the same time, would not deny that the authors of practically all of them pass over in silence such important and essential particulars as volume and weight. . . . However, without a knowledge of volume and weight, we cannot reproduce with any certainty the desired phenomenon, even though it has been obtained before by others." (4).

A more intimate picture of Lomonosov's experiments may perhaps be obtained from other sources. In a report (1745) on the building of his chemical laboratory, Lomonosov describes his future experimental work. He emphasizes the use of "pure substances." "Substances required for chemical work should be purified with all care in order that there may be no foreign admixture . . ." Then it is necessary "to investigate the specific gravity of native and produced substances. . . . Parts of substances in small quantities and all others, where it is possible, should be examined under a microscope. . . . Chemical experiments should be supplemented by optical, magnetic and electrical ones, because, not only from the experiments of others, but also from my own experience, I have come to the conclusion that only when chemical experiments are united with physical experiments, are they especially effective." The report ends with a statement that "in all the above mentioned experiments, I will note and write down not only the effect of the weight and volume of the substances and vessels used, but also the environment itself. . . ." (5).

From 1751-1753, Lomonosov delivered a course of lectures, which he called "True Physical Chemistry." Physical chemistry according to him "is a science explaining on the basis of physical laws and experiments, changes occurring through chemical operations in complex bodies." (6).

Lomonosov proposed to make the physico-chemical investigation of aqueous solutions of salts, under the following headings:

(a) Solubility at different temperatures.
(b) Density of saturated solutions at different temperatures.
(c) Increase of volume during dissolution.
(d) Lowering of temperature in process of dissolution.
(e) Expansion of solution from 0° to 100°.
(f) Ebullition temperature of solutions.
(g) Heat capacity of solutions.
(h) Dissolution of salts in saturated solution of other salts.
(i) Congelation of solutions.
(j) Refraction of light in solutions as compared with that of water.
(k) Rise of solutions in capillary tubes.
(l) Microscopical observations of solutions.
(m) Action of electrical force on solutions.
(n) Color of electrical sparks produced in solutions.
(o) Crystallization of solutions and investigation of crystals obtained.
(p) Deliquescence of salts. (7).

Little is known about the realization of this gigantic program. Without any doubt, we must agree that this program lies at the very base of our physico-chemical knowledge and, we might conclude with little hesitation, that Lomonosov has well earned the title of the founder of physical chemistry. His other contributions perhaps bear no less prophetic witness to this fact than the foregoing outline. Possibly, Lomonosov's greatest single contribution is his mechanical theory of heat and certain applications which he was able to derive from it.

His basic supposition is not original. Lomonosov, like others before him, assumes that matter is composed of indivisible small particles or molecules. He refers to them as "insensitive particles," trying to emphasize by this name the impossibility of acknowledging the existence of such particles by direct means. According to Lomonosov, these particles are spherical and are in continuous rotary motion. In his "Reflections upon the Cause of Heat and Cold," (Section 9), he speaks of his theory as follows: "Motion may be general, when a body changes its place, and internal when there is motion of insensitive particles of matter. Consequently, heat consists of the internal motion of matter." (8). This supposition is further developed in the "Discussion of Solidity and Fluidity of Bodies" (1760): ". . . . from the theory of rotary heat-generating motion it follows that the particles of warm bodies revolve faster (than those of cold bodies), and strike each other with greater force. Consequently, their adhesion decreases, the more warmth or heat the body possesses. It might be heated to such an extent that it would not only be transformed into a liquid, but its particles being separated and having lost mutual contact, would be dissipated into vapor . . ." Where is the lower limit of heat? ". . . . According to the theory of heat-generating motion, the body has heat so long as its particles move in rotary motion, even though they may seem cold." (9).

We have here all the basic conceptions of kinetic theory and its application to the phenomenon of liquefaction and evaporation, and perhaps even a notion of the absolute zero.

Following the same trend of thinking, Lomonosov comes very near to a fundamental conclusion, which is known at present under the name of the Law of Conservation of Mass and Energy.[4] "All changes occurring in nature are such that when something is taken from one body, as much is added to another. So, when there is a decrease somewhere in matter, there will be an increase in some other place: for as many hours as one stays awake, by just that number of hours has one's sleep been curtailed. This general natural law projects itself into the rules of motion, because when a body by its force moves another one, it loses as much force as it communicates to the body receiving the motion." (10).

The first part of this statement cannot claim originality, since Roger Bacon (1560-1626) in his *Novum Organum* comes to a very similar conclusion: "There is nothing more true in nature than the double proposition that nothing is made from nothing, and nothing is destroyed. The true quantity of material, or a total sum of it, remains invariable, not increasing or decreasing." The second half, dealing with motion, is

4) First expressed in a letter to Euler on the 28th day of November, 1748.

of greater interest, though foreshadowed by Newton's experimental law of impact. The question is, what did Lomonosov mean by "force of motion." Unfortunately we do not possess any more accurate definition by him, but we have indirect evidence indicating that Lomonosov meant the quantity of motion, *i.e.*, the product of mass and velocity. Rumovsky, a student of Euler, writes in a letter (December 7, 1756), that "he (Lomonosov) proves that the quantity of motion is not proportional to the mass multiplied by the square of the velocity." (11). Further evidence that Lomonosov spoke in a quantitative manner may be obtained from the following statement in his dissertation, "Upon Chemical Solvent in General" (1748): "When a body accelerates the motion of another, giving it part of its motion, it does it in such a way as to lose the same amount of motion." (12).

In the time of Lomonosov, one of the most debatable questions was the phenomenon of combustion. The experiments and teachings of Jean Rey (1630), John Mayow (1674) and Robert Boyle, in the end of the 17th century, were presumably known to Lomonosov. His natural curiosity was especially aroused by the experiments of the latter. The *principium inflammabile phlogiston* was in vogue: like ether in the physics of modern times, *phlogiston*, two centuries ago, did a number of marvelous things. According to Boyle (1673) this substance of fire was able to pass through glass, and uniting with metal, to form an oxide. His experiment was simple: Boyle took a glass retort, placed in it lead or tin, and then sealed the neck. The retort and the metal were then weighed; after two hours' heating, the metal formed an oxide. Then Boyle broke the neck of the retort, upon which the air rushed in, and then weighed the retort again. He found a noticeable increase in weight.

Lomonosov repeated this experiment with one modification: after heating he weighed the retort without opening it, and found no increase in weight, from which he inferred (1756) that the "substance of fire" did not pass through the glass. Lomonosov concludes that "by these experiments it was found that the opinion of the eminent Robert Boyle was incorrect." (13).

In the summary of a report made to the Academy (in 1760), he further emphasizes that it "was proven by me . . . that Aristotle's elementary fire, or, according to modern scientists, a special heat-generating substance which passes from one body to another, wandering without the slightest plausible reason, is only fiction. I firmly declare that fire and heat consist of the rotary motion of particles of the matter composing their bodies." (14).

Such were the far-reaching statements of this remarkable man. They all met with more or less disapproval by his colleagues, and among all of them, perhaps Euler alone realized their significance and was the only one to encourage Lomonosov.

Though denouncing Boyle for his theory of oxidation, Lomonosov paid considerable attention to his experiments on the "spring of the air and its effect." Having built a mechanical explanation of heat, it was not difficult for Lomonosov to apply his theory to the property of gases. His conclusions, which appeared under the title of "An Attempt to Formulate the Theory of the Elastic Power of Air," coincide with our modern theory of gases. One of his inferences is, however, worth noting. On purely theoretical grounds, Lomonosov came to the conclusion that a gas will not obey the Boyle Law at high pressure: the volume occupied by the molecule would become apparent and would involve a correction. This fact was acknowledged 115 years after Lomonosov made his inference, and as we know, satisfactorily shown by Vander-Waals.

Lomonosov was interested in the nature of light quite as much as in the theory of heat. The mechanical model devised by him to account for the properties of light, though ingenious, did not survive the test of time. An account of his theories is given in "A Word About the Origin of Light, Offering a New Theory of Colors" (1756). "Light and heat come from the sun," says Lomonosov, "from which we must conclude that both are produced by the same substance, though by different motions." (15). Dismissing as impossible Newton's corpuscular theory of the propagation of light, he proceeds as follows: "Since ether produces heat (a rotary motion of particles) in terrestrial bodies, it must contain that motion in itself. Ether cannot have a streaming motion, while rotary motion produces heat without light; therefore, there remains only a third possibility: a wave motion of ether, and this must be the cause of light." (15). It is, indeed, a rather fine piece of logic, and perhaps we must give credit to Lomonosov for choosing, from many current hypotheses, the one which proved itself to be of greatest value.

His mechanical scheme of the composition of light is in many ways unsatisfactory to us. According to Lomonosov, the ether is composed of spherical particles. There are three kinds of these, differing in size: the largest packed as close as possible, hold between themselves smaller particles. In the spaces left between the spheres of the smaller are similarly located spherical particles of still smaller size. All of these three sizes of spheres have independent rotary motions.

"Finally I find," writes Lomonosov, "that from the first kind of ether (the largest particles), comes the color red, from the second—yellow, from the third—blue. Other colors arise from the mixture of these three colors." (16) Then, he emphasizes that: ". . . the motion which produces heat and color is a rotary one: the substances (in which the motion is produced in these two cases) differ." (17).

The scheme is a rather complicated one, and was made still more so by further assumption, necessary to account for the transmission of heat and color from the ether to the tangible matter.

We shall not attempt to describe this scheme here, but will pass to the subject of atmospheric electricity in which Lomonosov was interested as well as Benjamin Franklin.

In June 1752, Russians learned of the discoveries of the American scientist. A member of the Academy of Science, Richmann, undertook to repeat Franklin's experiments, and for this purpose built a suitable device for capturing spheric electricity. Lomonosov also built at his house a very similar "thunder machine." All went well until July 26, 1753. On this day, during a conference at the Academy, Richmann saw the beginning of a thunder-cloud and hurried home. There, according to a witness, he was standing about one foot from the machine, when a blue, fiery ball made its appearance, struck the professor directly on the forehead and he fell dead without a sound.

This sad incident produced a storm in the Academy. Lomonosov wanted to deliver at once an address giving a scientific explanation of atmospheric electricity; other members opposed him, some because of personal antipathy, others on the ground that it was not fitting to hold a scientific meeting so soon after the death of one of their colleagues. Finally, the address was delivered on November 25, 1753. Its chief point of interest lies, perhaps, in Lomonosov's explanation of the origin of atmospheric electricity.

In 1751 and 1752, Lomonosov carried on numerous measurements of the density of air at different temperatures. These studies brought to his mind the supposition that in the atmosphere there exist not only horizontal currents of air, but also vertical ones. In continental countries thunder storms are likely to occur between three and four o'clock in the afternoon, when the hot air near the earth rises to higher regions. Lomonosov writes: "Who will doubt that in the summer, water vapors, being heated by the sun, fly against each other causing friction? . . . It is highly probable that the electrical force in the air originates from the heat and friction of these (water) vapors." (18).

According to Lomonosov, sudden frosts and thunder storms have a very similar origin, the only difference being that in the case of sudden frosts, there is a descending current of cold air. Lomonosov, in support of this theory, calculated the density of air at various temperatures, and thus found conclusive proof that cold air, being heavier, must tend to descend to the surface of the earth.

In many ways, Lomonosov's ideas on meteorology were very like those of Franklin. However, he defends his independent discoveries as follows: "The ascending and descending currents of air were briefly mentioned by the illustrious Mr. Franklin in his letters. However, I do not owe him anything, since I first thought and spoke about descending currents of air several years ago, and saw Franklin's letters for the first time when my speech was already written, to which fact my colleagues will bear witness. Secondly, the descending currents of air were mentioned by Franklin in a few words as a guess. I deduced my theory from sudden severe frosts, phenomena unknown in Philadelphia where Franklin lives. . . . I do not add all this here because I wish to outshine (Mr. Franklin), but because of the wishes of my colleagues, who advise me to annex this for my justification." (19).

An Experiment in Electro-Physiology.

This experiment is described by Lomonosov as follows: "On the third of last August, when the sun was setting, I connected an American sensitive plant (*Mimosa pudica*) to an electrical machine. Its leaves were already closed, and after repeated touching by the hand, they contracted so much that upon further touching there was no more reaction. When the electrical machine was put into action, so that sparks jumped to one's finger, then the leaves, already much contracted, reacted again when touched and contracted still further. After repeating this experiment many times, I was convinced, with pleasant surprise, that the sensitive (plant) is revived by the stimulus of electric force and that its sensitivity has some relationship to it." (20).

Contribution to Astronomy.

The Newtonian reflectors were known to Russians of Lomonosov's time. A concave paraboloid of glass, silvered on its curved surface, forms the objective of these reflecting telescopes. Newton placed a small mirror on the axis, which reflected the rays out through the side of the telescope, and the image was then seen through an eye-piece.

This second mirror had one drawback: it obstructed some of the incident light, and Lomonosov conceived a rather simple idea. He inclined the paraboloid mirror a few degrees, so that the image fell at the side of the body of the telescope. This modification of Newton's reflector described in Latin by Lomonosov's "A Speech on the Improvements of Telescopes" (1762), (21) is usually credited to Herschel (1789).

The night of May 26, 1761, was anxiously awaited by astronomers of Europe and Russia. On this date was due a rare phenomenon, which will not occur again until 2004: the passage of the planet Venus over the disk of the sun. The Academy, besides making preparations to observe the phenomenon in St. Petersburg, sent two expeditions to Siberia.

Lomonosov observed this event from his house. He and other scientists in a joint report to the Academy, expressed their observations as follows: ". . . the Councillor Lomonosov states that the planet Venus is surrounded by considerable atmosphere, similar (perhaps even greater) to that which surrounds our earthly globe. This is so, because, firstly: before the entrance of Venus over the surface of the sun, there was a loss of visibility of that side of the sun. . . . When Venus was leaving (the sun), the contact of its front edge produced a prominence. This could only indicate a refraction of the sun's rays in the atmosphere of Venus."(22).

The observation was correct.

Contribution to Geology and Mineralogy.

Though the science of minerals may be called one of the oldest in Europe, before the time of Lomonosov Russians had only a scattered knowledge of this useful art. As we remember, Lomonosov went to Germany primarily for the purpose of studying mineralogy and assaying, although upon his return to Russia, he applied himself mostly to sciences having a greater theoretical significance.

His chief contribution was perhaps the fact that he transported bodily to Russia the contemporary knowledge of geology, mineralogy, as well as metallurgy. Beside this passive role, his restless mind could not avoid being drawn into the mystery of the origin of the metals of our earth's crust. His contribution to these subjects may be found in his essay, *A Word About the Birth of Metals from the Movement of the Earth.* (1757), and his book, *First Elements of Metallurgy and the Knowledge of Ores,* with two supplements: *About the Free Movement of Air in Mines* and *About the Strata of the Earth* (1763).

The plan of the *Strata of the Earth* is remarkably modern: Chapter I. contains "The Form and Relief of the Earth"; Chapter II, "Rocks and the Form in Which They Exist in Nature"; Chapter III, "Changes of the Earth's Surface Due to Wind, Water and Ice"; Chapter IV, "Changes Which Are Connected with the Shaking of the Earth, *i.e.,* The slow prolonged rise and fall of the earth's crust"; Chapter V contains the concluding part.

The expression "shaking of the earth" is especially interesting. Lomonosov includes in this definition not only earthquakes proper, but also the prolonged rise and fall of the earth's surface and the formation of mountains.

The tectonic and volcanic processes have one origin, according to him. Their cause is the changes occurring inside the earth. The mountains are made of strata formed in the sea, as they contain shells by various mollusks. These strata, necessarily, were first horizontal, but rose to various heights. According to Lomonosov, the continents are surrounded by the sea, but not the sea by continents. He writes: "In some places the shores, due to the receding of the sea, increase so much that some scientists question where the water is distributed. . . The question is futile because, due to changes in the earth's crust, its surface may rise in one place and be depressed in another without changing the level of the water. Doesn't nature suggest by the powers confined in the heart of the earth, the forces upon which depend the rise and fall of its surface? Doesn't she proclaim that a plane upon which people travel, dwell, build villages and towns, was long ago the floor of the ocean, though now it lies far from it . . . even as much as 300 *versts?*" (23).

The movements of the earth are the cause of the ore-bearing veins. Solutions of metals run through the cracks of the earth, forming veins. "All these veins are produced by the shaking of the earth." (24).

In the essay on the origin of metals, Lomonosov writes: "In the second place stand the fatty substances found in the earth, such as slate, coal, asphalt, rock-oil and amber. It is evident that all of these as well as other substances related to them, were produced by disintegration. Thus, slate is nothing more than mould, formed from decayed herbs and leaves, washed from fertile ground and forests, which in the old days settled on the bottom of the lakes like slime. The lakes dried and filled up with sand, and the slime solidified in time into slate. . . . As for amber, one wonders how some learned people, great in name and service, can consider it a mineral. They do not take into account the large number of animals, not to mention the multitudes of leaves, imprisoned in it; all these oppose this explanation, seeking to proclaim aloud that they were caught by the liquid resin that was shed by the trees, surrounded by it and left imprisoned." (25).

This is probably one of the finest pieces of Lomonosov's thinking; it witnesses again his strong desire to let objects tell their own origin, rather than to assign one to them. It is typical of him.

Such are the contributions of Lomonosov in the field of natural science. If we take into account his contributions to poetry and philology, which are no less significant than his contribution to science, we may, without hesitation, agree with Pushkin that Lomonosov was a university in himself.

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A complete bibliography in Russian on Lomonosov may be found in Vol. VI of the Description of the Exhibition: "Lomonosov and the Time of Elizabeth" (*Vistavka Lomonosov i Elizavetinskoe Vremya,* published by the Russian Academy of Science, Petrograd, 1918). A review of the translations and works on Lomonosov in German, English, French, Italian and Swedish is to be found in Vol. VI of the same work, (Petrograd, 1915).

For the sake of clearness, words and sentences in brackets have been introduced by the writer in the quotations from Lomonosov.

For the transliteration of Russian words, we have adopted the system commonly used in England and in this country. It differs from that adopted by a group of editors in England (*Nature,* February 27, 1890); we have transcribed the fourth letter of the Russian alphabet by "g," they by "gh"; the twenty-third by "ts," they by "tz"; the twenty-eighth by "y" in place of "ui." The short Russian "i" is transcribed here also by "y."

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