THE ACHIEVEMENT OF M. V. LOMONOSOV IN THE FIELD OF AUTOMATION OF MEASUREMENTS

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Usp. Fiz. Nauk 75, 411-420 (November, 1961)

"In nature measure and weight are the chief instruments of knowledge" (D. I. Mendeleev)

"NEW methods of measurement indicate real progress." This laconic description of the role and significance of measuring technique, which was given by the distinguished Russian scientist B. S. Jacobi over a hundred years ago, has become especially weighty and noticeable in our age, an age of grandiose achievements in science and technology and of a vigorous development of mechanization and automation of production. It can be said without exaggeration that present-day measuring apparatus and the means of automation have become the material basis without which the further development of science, production, transport and agriculture are impossible.

The history of the techniques of measurement shows that several wonderful ideas and principles, which have found wide application in different realms of present-day human activity, originated long ago and, in particular, as a result of the creative genius of our countrymen.

In their desire "to lighten the load for our future," to uncover the deepest relationships in the natural phenomena observed, many generations of Russian instrument makers ventured and built, enriching by their creativity, by the invention of new means and methods of measurement, the science and technology of their fatherland and of the world at all stages of their development. This is most clearly seen in the immortal work of the great son of the Russian people, the scientist and encyclopaedist Mikhail Vasil'evich Lomonosov, who "left to his fatherland for all time an example of how science can and should serve the nation" (S. I. Vavilov).

Lomonosov's many-sided inventiveness is a brilliant example of the unity of science and the practical. Developing various theories in the realms of physics and chemistry, carrying out gravimetric observations and studying electrical phenomena in the atmosphere, the great scientist not only resolved the problem of the foundation and development of advancing natural science, but at the same time hastened to apply science directly to practice in order to develop the productive power of Russia and to strengthen its economic power. "Science, wrote Lomonosov in his Essay on the Use of Chemistry, presents a clear understanding of matter and uncovers hidden actions and the causes of properties; production uses them to increase human welfare" (Vol. II, p. 351)* The scientist perfectly understood, in equal measure, the great significance of the development of all aspects of human practice for the progress of science, and always used in his inventiveness the successes achieved in production, technology, agriculture and navigation. "Science shows the way to production" said the scientist; "production speeds the rise of science" (Vol. II, p. 351).

Knowing the large and strict demands presented to science by production, agriculture, navigation, and military affairs, Lomonosov always strived for any scientific theory to be tested by experiment, and relied on experiment. "I place experiment alone above a thousand opinions, born only in the imagination" (Vol. II, p. 125), the scientist wrote in his "Notes on Physics and Corpuscular Philosophy," having in mind many scientists of his time who often forgot the experimental roots of scientific knowledge. At the same time Lomonosov often warned of the danger of being carried away one-sidedly by experiment, and stood up for the rights of theoretical ideas in natural science and laughed sarcastically at those who "all their days make darkness with smoke and soot and in whose brains chaos reigns from the mass of unthought-out experiments." And in the fine lines which are still attractively fresh in "Discussion of High Accuracy of Navigation" affirming the principle of the indivisible unity of theory and experiment: "To establish a theory from observations, to correct the observations through theory, is the best means of all in the search for truth" (Vol. IV, p. 163).

Placing progress in science and practice in direct relation to the development of experimental skill, Lomonosov achieved the highest harmony between experimental and theoretical studies in his work. In a number of realms his achievements in experimental study acquired an unusually wide range. It is sufficient to say that in seeking ways to color glass the scientist carried out over three thousand experiments with a detailed description of each. Many more such examples could be given. The majority of his work bears the stamp of classical experiments. In them are united great significance of the results with original and

*Here and later we give in the references the volume and pages of the full collected works of M. V. Lomonosov, published by the U.S.S.R. Academy of Sciences in 1950-1957.

clever experimental method. The deep understanding of the unity of experiment and theory, and the brilliant embodiment of this unity in his scientific investigation of the roots of a scientific problem, raised Lomonosov far above his contemporaries, and visions of the development of natural science for many decades ahead opened to his glance.

Correctly resolving the problem of the relation of theory to practice and of theory to experiment, Lomonosov, as his manuscripts and printed heritage which have come down to us testify, devoted much energy to the technique of experiment, to the improvement of methods of measuring, and during the quarter century of his many sided achievement designed several tens of new instruments, unknown to 18th century science in the fields of astronomy, navigation, gravimetrics, meteorology, optics, physics, chemistry and others which, in the scientist's picturesque phrase, were necessary for him in order to "test everything that it is possible to measure, weigh and determine by calculation."

However, the significance of Lomonosov's creativity in the field of apparatus building is not merely determined by the great number of new measuring methods invented by him. A clear-sighted scientist, indefatigable toiler, and seeker of new unknown paths in science and technology, Lomonosov sought in every way for the automation of measurements, as a careful study of his works shows. In Lomonosov's view, the automation of measuring techniques should achieve objectivity and high accuracy of measurement, lighten and render less dangerous man's labor in many fields of practical activity, but mainly would open up wide possibilities for the development of experimental work in all branches of natural science, even with the small number of qualified investigators in Russia in the middle of the 18th century.

Lomonosov started his activity in automation of measurements with the invention in 1748 of a recording directional anemometer. This was not by chance. The problem of weather forecasting worried the scientist from the very outset of his scientific career. In his view it was a matter "worth mountains of gold." Besides, meteorology in Lomonosov's time was only in embryonic stage and "knowledge of the atmospheric cycle" was "hidden in great darkness." The reason for this, as the scientist correctly concluded in his "Notes on Atmospheric Phenomena, Produced by Electrical Forces" was "the unreliability of instruments designed for the purpose, the difference in conditions, observers of unequal carefulness, and a great mass of disorganized observations" (Vol. III, p. 25). Under such historically imposed conditions in meteorology there could be no question of scientific weather forecasting. According to the deep conviction of Lomonosov, to uncover the secrets of the weather and thereby solve one of the most important problems for mankind it was first essential to improve existing instruments radically and to invent a number of new, more reliable meteorological instruments. The idea of achieving full automation of the measurement of all the most important elements of meteorological observations was especially tempting. In spite of the apparently great difficulty in realizing such a complicated idea, Lomonosov nevertheless decided to achieve it and started with the invention of a recording directional anemometer, the need for which had long been ripe.

In the upper part of the recording anemometer invented by Lomonosov there was, as is seen from Fig. 1, a receiving arrangement in the form of a large cogged wheel, consisting of sixteen beech cogs, securely connected together by two iron wires ccc and gg. At any given moment half of the cogs are shielded from the wind by the wooden box BCED, together with which the wheel is oriented to the wind by the large vane Q. The recording arrangement was at the base of the instrument and this made possible not only the automatic determination of the wind direction, the measurement of its velocity, and determination of the sum of the velocities over a known time interval, but also allowed the determination of the sum of the velocities for every point of the compass separately.

This design of a directional anemometer by Lomonosov, which was thought out "exceptionally cleverly" according to the German physicist Munk, distinguished it favorably from the earlier anemometers designed by Christian Wolf (1709), Leitman (1725), and other scientists. In addition, the great perfection in construction of the recording directional anemometer invented by the Russian scientist was unsurpassed for a long time and was copied at the end of the eighteenth and the beginning of the nineteenth centuries in several countries (it is now difficult to establish whether following Lomonosov's idea or independently) in several modifications, kinematically very close to Lomonosov's directional anemometer.

Starting with the invention of the recording directional anemometer, Lomonosov apparently invented and made several other new automatic meteorological instruments during 1748-1751. Not one of them survives to this day, unfortunately, nor have any descriptions come down. However, it is reliably known that with the help of these automatic instruments the scientist organized in St. Petersburg in 1751 the first "meteorological observatory with recording instruments" in Russia and, probably, in the world. Three years later (1753-1754) Lomonosov built a second meteorological observatory in Ust'-Ruditsy, outfitting it, as in the first case, with several automatic instruments invented by himself. In a letter to Leonard Euler, who was then living in Berlin, Lomonosov wrote on February 12, 1754 "... I am building a dam, a mill and a saw mill, with a recording meteorological observatory rising above them, a description of which I will publish in the summer, with God's help" (Vol. X, p. 502).

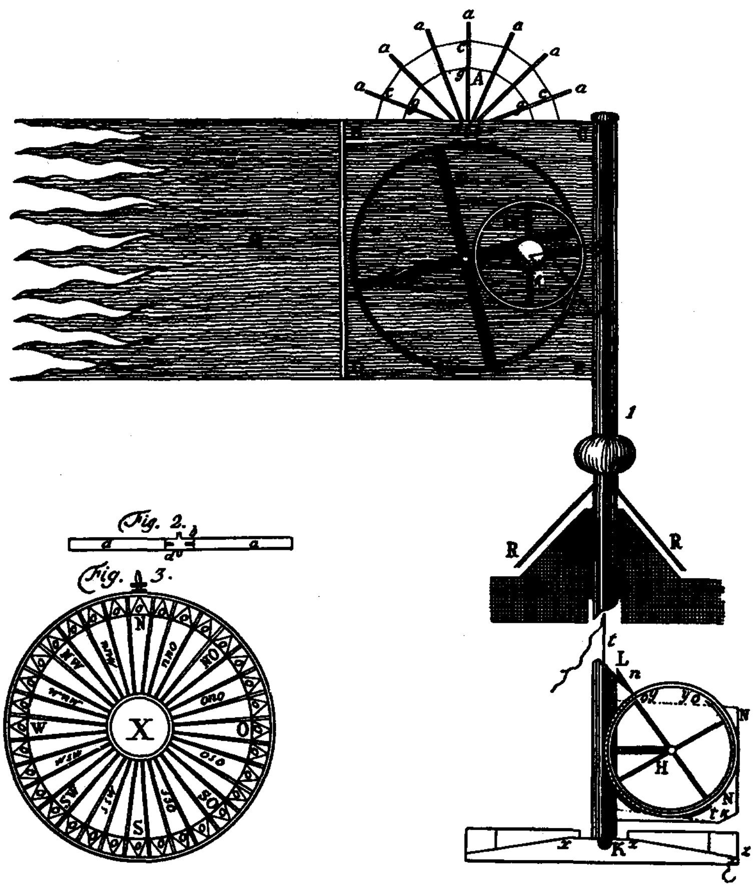

FIG. 1. Directional anemometer (drawing by M. V. Lomonosov).

These lines show that the recording instruments constructed by him were novelties and, in his opinion, should have been of interest to a wide circle of foreign investigators.

Apparently Lomonosov, for a lack of time, published no information about his recording observatory and instruments, but in "Monthly Notes of the Academy of Sciences" he published results of his meteorogical observations for the period from 1751 to 1755 "so that similar observations be made in other parts of the Russian Empire."

While laying the foundations of the science of meteorology, Lomonosov understood very well that the variations in weather were so great, and local conditions influenced its character so strongly, that even some tens of observatories furnished in the best way and with the best observers would be helpless in solving such a complex problem as the forecasting of weather. An exceptionally large number of observation points, well fitted out with instruments, were essential for a proper study of the weather and in 1759 Lomonosov put forward a bold plan in the pages of "Discussion of High Accuracy of Navigation" to build "... recording meteorological observatories in different parts of the earth in different regions, the placement and construction of which, with many new instruments, I have long ago thought out..." (Vol. IV, p. 293). In this way the great Russian scientist anticipated the idea of Lavoisier and Borde by twenty years and the suggestion of the German meteorologist Lambert by twelve years, on the organization of an international weather service, and was evidently the first among the scientists of the world in originating all-inclusive automation of measurements in the realm of meteorology.

Still another important credit in the history of meteorology is due M. V. Lomonosov: he was the first to put forward the idea of the necessity of a systematic study of the upper layers of the atmosphere. For the practical realization of this idea, Lomonosov in 1754 designed and prepared a small flying apparatus, which he called "an aerodrome machine." This apparatus, with the help of wings moving in a horizontal plane by spring power, was to lift to the upper layers of the atmosphere recording meteorological instruments especially built for small scale measurements. Lomonosov thus built the first miniature helicopter long before Paukton (1768) and Bienvenu, and at the same time took the first steps in founding aerological methods. Fifty years later (in 1804) the Russian scientist, academician Zakharov first went up into the atmosphere in a free balloon in order to cary out aerological observations and thereby to carry out Lomonosov's great idea.

In talking about Lomonosov's work in the field of the automation of measurements, one cannot fail to include his invention of an apparatus, extremely simple in construction and original in conception, designed "to determine the maximum electrical action of the forces of thunder, without using sight or tubes, . . . and at different places and very far apart" (Vol. III, p. 121).

This apparatus is shown in Fig. 2: ab is a fine wire spring, c is a light metal disk and d is a wire with springs. In his essay "Remarks on Aerial Phenomena" Lomonosov described the principle of the action of the apparatus invented by him in the following way: "The electrical force entering the metal tube drives the disk from the cavity with a repulsive force, and the greater the force the more of the straight wire will come out of the cavity.* At the end of this action the straight wire cannot push itself back, since the springs and the teeth do not allow it. At a convenient later time everyone can see how large the largest thunder force has been" (Vol. III, p. 121).

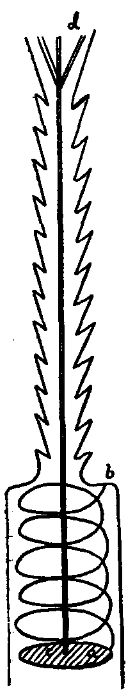

FIG. 2. Drawing of "an instrument which can determine the greatest electrical action of the force of thunder," proposed by M. V. Lomonosov.

Speaking in modern terms, this was a peak electrostatic voltmeter, in which Lomonosov was evidently the first to use a spring to provide a restoring moment.

The search for new methods of navigation and the invention of navigational instruments occupied a large place in Lomonosov's inventiveness. This was quite natural. Being born near the sea, he knew perfectly the difficulties of travel by ship, due to insufficient study of the seas and oceans, the changes of natural conditions, the primitiveness and inaccuracy of navigational instruments used, and in his concern for the progress of Russian sea travel he considered it his primary obligation as a scientist and patriot "to increase the safety of shipping by useful new inventions."

*Receiving an electric charge of the same sign, the coils of the spring repel one another, carrying down the metal disk attached to the rod–I. L.

According to very incomplete data, he developed and invented at different times more than twenty navigational instruments, including a sextant with artificial horizon " a sea rod—an instrument for determining the time accurately at sea," a recording compass, and many others. The construction and principal of operation of each instrument were described by the scientist in his well known work "Discussions of High Accuracy in Navigation." A careful study of this work and of the whole gamut of navigational instruments designed by Lomonosov shows that he was aiming at maximum automation in the measurement of all the most important navigational parameters. In carrying out this bold and, in view of the low level of technology in the middle of the 18th century, difficult problem, neither the difficulties nor the possibilities of bitter disappointments daunted the scientist. "In this matter" wrote Lomonosov in the introduction to the "Discussions," "I followed the prospectors who are maintained by sweet hopes without any certainty, but not always in vain. I thus put forward, putting aside any doubt, everything that I have thought out, invented and produced for this purpose" (Vol. IV, p. 126).

Of the whole complex of navigational instruments invented by Lomonosov, the group designed for reckoning the course of a ship in overcast weather when astronomical orientation is not possible is of undoubted interest. Thus, for example, "so that the master of the ship should know all the errors which arise by oversight of the helmsman," the scientist proposed "a special recording compass." As can be seen from Fig. 3, the compass invented by Lomonosov made possible the automatic tracing out on a paper chart all the deviations of the ship from a given point of the compass, by means of a pencil fastened to a bobbin and a clockwork mechanism. In order to avoid complicated calculations, Lomonosov proposed the following ingenious method for integration by weight: the paper chart (assumed to have uniform density) is cut in two along the traced curve and the two parts are weighed in turn. The difference in weight of the two parts shows the direction of predominant deviation of the ship from its course.

The recording compass invented two hundred years ago by Lomonosov was, thus, none other than a recording course indicator. This kind of instrument has, as is well known, wide application in present day sea travel. In fact, the principle of Lomonosov's instrument lives on in all course plotters of our day.

Lomonosov also considered it essential to take into account the action of a side wind on the hull of the ship in order to determine its exact position on the sea, and invented a special instrument for this purpose, which he called "klizeometer" (Fig. 4), i.e., an inclination meter (Greek). In the first variant this instrument consisted of a quadrant Q, a pointer h with needle F, a line k about 300 feet long and a stick *l*, designed to be let into the water. As the ship moves the line was supposed to turn the pointer by the corresponding angle

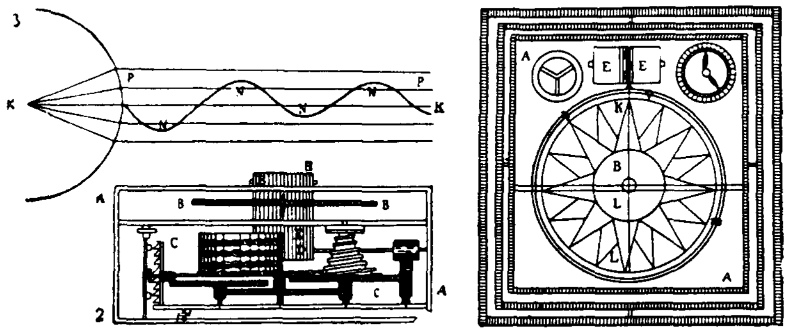

FIG. 3. Drawing of a recording compass invented by M. V. Lomonosov (the first course plotter in the world).

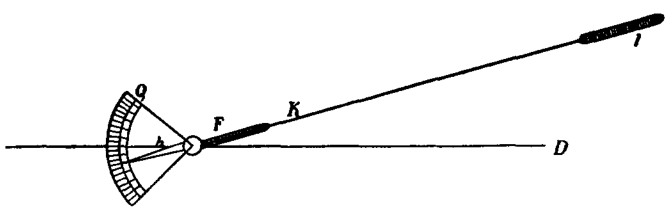

FIG. 4. Drawing of the "klizeometer" invented by M. V. Lomonosov—and instrument to determine the deviation of a ship under the action of the wind (drift).

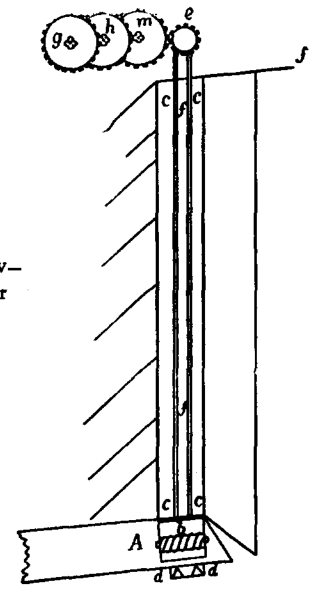

FIG. 5. Drawing of the "dromometer" invented by M. V. Lomonosov—the first base log-line of the impeller type in the world.

of movement of the ship. The scientist later decided to improve the "klizeometer" and proposed "to join a simple watch spring to it, as in... a compass" (Vol. IV, p. 153). By providing a recording mechanism for his "klizeometer," Lomonosov produced a drift recorder which made it possible to fix legibly on a paper chart the deviation of a ship from its course under the influence of the wind.

By the aid of the recording compass and drift recorder it was thus possible to plot on a map the direction in which the ship was sailing. However, it was still necessary to know the speed in order to calculate a ship's route. In Lomonosov's time the method for this was extremely primitive: a hemp rope log line with a small board at its end was used, having knots placed at even distances along the whole length of the line. In order to do away with this antiquated and slow means of measuring a ship's speed, the scientist devised an original "machine" which he called a "dromometer" (Fig. 5). The impeller of the dromometer A was set up at the bottom of the boat, under the keel, and rotated continuously under the action of the water as the boat moved; by means of a belt its rotation was transmitted to a system of gears, which had pointers on their shafts marking off on dials the distance travelled in miles and even tenths of a mile.

It can be seen from the drawing of the "dromometer" and the description of the principle of its action that Lomonosov was successful in producing an automatic measurement of the distance travelled by a boat with this mechanical log of a rotating type. Such logs found a wide application in the 19th century, and even the present day Chernikeev log is based on the same principle as Lomonosov's machine.

In trying to increase the accuracy of the calculated distance covered by a boat, Lomonosov even decided to take account of the correction for the motion of the sea, which caused the body of a boat to move in a wavy line and not straight. The "tsimatometer" (apparently from the word κυμα —a wave) invented by the scientist for this purpose is shown in Fig. 6. The board BB is set up in a vertical plane, parallel to the keel. The weight A will then turn around the axis c as the keel rolls. As the right-hand edge of the board lifts up, the post cA, on which the weight hangs, remains in a vertical position but the gear c turns by an angle equal to the inclination of the keel. On the other hand, when the left hand edge of the board BB lifts, the weight A will strike the rod i, inserted in the board gg; after each such stroke the gear wheel M at the bottom will advance one tooth. In his "tsimatometer" Lomonosov was thus able to realize an idea which was very interesting in a constructional sense —the same pendulum made it possible to register on a dial the sum of all the angles of inclination of the roll of the keel, while the counter registered the number of all the swings of the ship which went to make up this sum. Dividing the former by the latter number, the steersman could calculate the mean roll of the keel

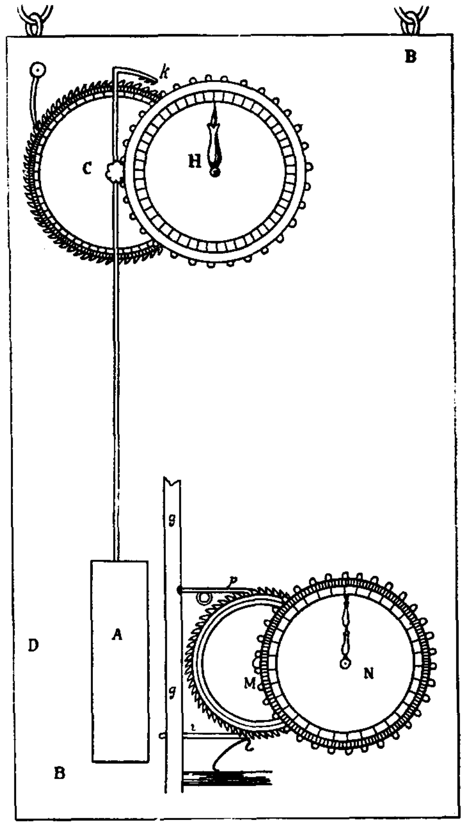

FIG. 6. Drawing of the "tsimatometer" invented by M. V. Lomonosov—an instrument for determining the motion of a ship under the influence of keel roll.

(in degrees) in one direction or the other, and make the corresponding correction to the distance travelled by the ship.

Experience showed, however, that the correction for the roll was negligibly small compared with errors in calculating the path that arise from a number of other, sometimes unavoidable, factors. Presumably the "tsimatometer" did not receive further application for the purposes which its author had in mind for this reason. The idea which went into the construction of this instrument has not lost its significance to this day. It is sufficient to say that primitive longitudinal side slip indicators used in present-day navigation do not possess counters. In conclusion, even now the idea of the "tsimatometer" could be applied successfully for finding the mean angle of heeling of a ship suitably by placing the instrument in a plane perpendicular to the keel.

In this way, by enriching the arsenal of navigational technology with automatic devices, Lomonosov laid the foundations of scientific sea navigation and of complete automation of the main parameters of shipping.

It was natural that, working on the solution of problems of the automation of measurement in different regions of science and practice, Lomonosov could not avoid being concerned in the improvement of the clocks existing in his day and in the invention of new ones. As Marx put it, clocks were "the first automatic devices, designed for practical purposes; the whole theory of the production of uniform motion was developed around them."

In this field, as in other realms of invention, Lomonosov left a deep impression. In 1759 he developed a sea clock—chronometer (Fig. 7). In order to reduce the effect of the spring on the motion of the clock and to attain a high accuracy in its readings (the elasticity of a spring decreases as it unwinds), the scientist equipped his chronometer, along with a helical drum construction (on which is wound a chain which transmits the motion to the mechanism), also with four springs instead of one. Each spring should be wound at a different time of the day, according to the intention of the author of the clock (at six hour intervals), thereby evening out the elasticity of the spring system of the chronometer.

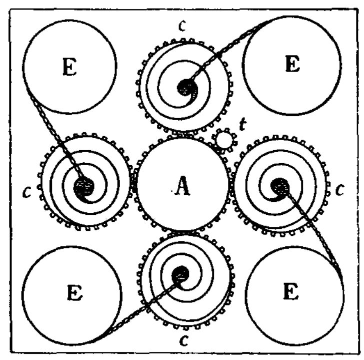

FIG. 7. Basic diagram of the ship chronometer invented by M. V. Lomonosov.

Lomonosov's idea about improvement in the hourglass, much used in the 18th century, is also extremely interesting. In order to "make astronomical observations of the ship's meridian" more accurately with the help of such clocks and "determine the longitude of a place," he proposed replacing the usual sand in them by fine silver shot and even developed in detail the technology of producing the latter.

Lomonosov was never satisfied with the projects of apparatus developed by him or the constructions of instruments and measuring apparatus invented and prepared by him, and continued to work tirelessly on their improvement. His "Chemical and Optical Notes" which has come down to us, are witness to this. There is a long list in them of the constructional and technological improvements which Lomonosov introduced and proposed to introduce into the instruments and apparatus invented and constructed by him earlier: reflecting telescopes, a ship's barometer, microscopes, thermometers, a ship's chronometer etc.

The chief significance of Lomonosov's inventiveness lies in the fact that, unlike the majority of his contemporaries, he designed and prepared his new instruments on a solid basis of deep and exact calculations, of numerous experiments and of all-out investigations. Thanks to this, many of Lomonosov's instruments not only went into general use even during their inventor's lifetime, but were ahead of their time and have not lost their significance even in our day.*

The conditions under which Lomonosov worked could not fail to influence his inventiveness. He was limited by the St. Petersburg Academy of Sciences in his means for experimentation; not having assistants and nearly always working simultaneously on the invention of several instruments, in order to give contemporary science and technology as many new measuring devices as possible, Lomonosov often had no time to bring all his creations to the desired degree of perfection. Some of his projects, therefore, remained undeveloped in construction and were not realized. Even so, there were few undeveloped projects. The overwhelming majority of the measuring instruments invented by Lomonosov, passing through the involved path from the engineering calculations to the experimental models and standing the test of time, have in the course of time become the "university" of Russian instrument makers. The best inventive traditions of the country's instrument manufacture have developed from Lomonosov's labors and continue now—the deep organic relation between science and practice, the tireless innovation and hostility to inertia and routine. We are right in concluding that he laid the foundation of the scientific construction and technology of making measuring instruments and automatic devices in Russia, and without doubt he can be called one of the originators of the automation of measuring techniques, which has had such a vigorous development in our time.

*See A. A. Eliseev and I. G. Litinetskii "M. V. Lomonosov—the First Russian Physicist," Fizmatgiz, 1961 M.–L.

Translated by R. Berman
58