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M. V. LOMONOSOV AND THE DEVELOPMENT OF PHYSICS

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M. V. Lomonosov, the first Russian academician and the founder of natural science in Russia, worked in physics in the middle of the eighteenth century.

The eighteenth century was the time when physics, after its emergence as an independent field of natural science, experienced the first period in its development. This period is characterized above all by the accumulation of factual material and the establishment, on the basis of this specific knowledge, of particular laws encompassing a limited group of physical phenomena.

The various physical forms of motion were studied separately. Physics was actually broken down into a number of subdivisions—mechanics, heat, electricity, magnetism, etc.—which developed independently without proper interrelation.

Such a divided study of physical phenomena was based on the then prevalent notion of so-called weightless materials. According to this idea, there was a specific weightless fluid for each physical form of motion (the caloric, light particles, electric fluids, etc.). Unlike ordinary matter, these materials were assumed to be unaffected by the force of gravity. Eighteenth-century physicists tried to explain all physical phenomena on the basis of this idea of weightless fluids.

In spite of the prevalence of this sort of opinion, echoes were still heard among mid-eighteenth-century physicists of another view on natural phenomena, Cartesianism, whose influence was responsible, to a considerable degree, for the process of freeing natural science from the medieval outlook.

Unlike natural scientists of the eighteenth century, Descartes (the founder of Cartesianism) considered it necessary to construct a general picture of nature according to which all physical and other natural phenomena were attributed to the motion of large and small particles formed out of one material. Unable to find support in any adequate experimental results, Descartes and his followers misused hypothetical reasoning which was either impossible to check or whose experimental verification yielded negative results.

Newton dealt the finishing blow to Cartesian ideas at the end of the seventeenth century. While the Cartesians tried to explain the motion of the planets and the force of gravity under the assumption that action cannot arise except as a result of direct contact, Newton took action at a distance as a premise. He based all of celestial mechanics on the law of universal gravitation, which gave a quantitative description of the interaction of bodies at a distance; however, Newton as a matter of principle refused to explain the mechanism of this law's action. The struggle between Cartesians and Newtonians ended with the victory of Newton and his followers, after which a general trend in physics based on the notion of weightless fluids took shape. Towards the middle of the eighteenth century it became the prevailing idea among physicists.

Only in the first decades of the nineteenth century did the situation in physics begin to change, with the evolution of a new approach to the investigation of physical phenomena. Gradually phenomena involving the transformation of some forms of motion into others began to be more and more widely studied. The concept of weightless fluids began to collapse. Its final liquidation occurred with the discovery and general recognition of a law of conservation and transformation of energy which bound together all physical processes. Physical phenomena were now represented as various forms of motion which could be converted into one another in definite quantitative proportions. At first these forms of motion were thought to be mechanical. The problem then was to examine the nature of these motions, and in the first half of the nineteenth century the efforts of physicists were applied to this end. It was only new discoveries at the beginning of our century which led to the recognition that this task could not be accomplished.

Lomonosov carried out his scientific work at the time when the concept of weightless fluids held sway in physics. The overwhelming majority of physicists of this time were already wedded to this concept. Only a few went their original ways. Lomonosov was prominent among these latter scientists.

Lomonosov as a physicist differed profoundly from his contemporaries for a number of reasons. He did not take the same path in science as the majority of physicists of his time. He rose above his time. With brilliant insight he chose a new road for science, a road which physics followed later, and with great successes, in the nineteenth century.

Lomonosov was able to suggest a number of new theses and hypotheses, and to make a number of new discoveries anticipating the achievements of physics of the following (or nineteenth) century. Consequently, his opinions in physics turned out to be closer to nineteenth century physics than to the physics of his own time.

Lomonosov was an implacable opponent of the concept of weightless fluids. He did not want to invent weightless materials, as was done in his time. The only weightless material which he recognized was ether. Ponderable matter, consisting of imperceptible little particles (as he called atoms) and ether—that is all that exists, and all the reality around us is made up of it, according to him.

Refusing to recognize weightless materials in defiance of the opinions of the majority of his contemporaries, Lomonosov considered all physical phenomena to be the result of the motion of large and small masses of ponderable material and ether. Such a point of view did not become the basis of the theoretical outlook of physicists until the second half of the nineteenth century. Towards this time the wave theory of light, which considered light as mechanical disturbances propagating in the ether, triumphed; the kinetic theory of heat began to evolve; and electromagnetic field theory, which at first represented electrical and magnetic processes as the result of mechanical motions in the ether, came into existence.

It is well known that, as far back as the mid-eighteenth century, Lomonosov was considering heat as the motion of the smallest particles of ponderable bodies. Moreover, he did not simply voice this idea; he substantiated it and wrote a whole study, "Reflections on the Cause of Heat and Cold," which developed his hypothesis to the status of scientific theory.

For a long time after Lomonosov, right up to the middle of the nineteenth century, the kinetic theory of heat did not progress at all. It is true that there were physicists, especially in the nineteenth century, who argued against the caloric theory and for the hypothesis that heat is the motion of atoms, but further than individual pronouncements they did not go.

The view that heat is motion was cited, on a par with the view that it is weightless material, in various physics courses, reference books, etc. For example, in one of the widely distributed nineteenth-century reference books, a physics dictionary compiled by Heller, in the article "Heat,"[1] various opinions on the nature of heat were set forth, among which Lomonosov's theory was rather thoroughly expounded. However, when presenting theories of heat as motion, it was usually observed that such opinions were obsolete, much as ether theory is today. This is the way the author of the article "Heat" in Heller's dictionary evaluated Lomonosov's theory.

Only in the middle of the nineteenth century did the kinetic theory of heat begin to develop and emerge as a whole new field of physics. It is interesting to note that many of these very first works on the kinetic theory of heat seem to be a direct continuation of Lomonosov's work, since they start out from the same specific opinions on the nature of thermal motion as he did.

Since Lomonosov did not recognize the existence of forces which act at a distance, he assumed that particles, being solid bodies, must be in contact. If not, in his opinion, the body as a whole could not exist. In connection with the structure of solids, Lomonosov also arrived at the idea that thermal motion in a solid, hence in all bodies, must consist of the rotational motion of its particles, since only by such a motion is the contact between particles not broken.

It is this general hypothesis of Lomonosov's about the nature of thermal motion (to be sure, no longer with the same basis as above) which we find in many of the first works devoted to the kinetic theory of heat in the middle of the nineteenth century.

For example, in a work of Joule's written in 1844,[2] where heat is treated as motion, the author assumes that these motions are rotational. Joule considers that the molecules in solids are surrounded by a certain electrical atmosphere. Heat, in his opinion, is the rotational motion of these atmospheres. Moreover, their angular rotational velocity is proportional to the temperature. Later, in 1851, comparing the hypotheses of rotational and translational thermal motion and employing the second, Joule nonetheless wrote: "I will proceed from the assumption that the hypothesis of rotational motion agrees equally well with the phenomena."[3]

The hypothesis that thermal motion is the rotational motion of the particles in a body was also very extensively applied by the English physicist and engineer Rankine, to whose credit are a great number of works on thermodynamics and the kinetic theory of matter.

In 1850 and subsequently,[4] on the basis of a hypothesis analogous to Joule's, he attempted to construct a molecular theory of heat and even give a molecular-kinetic interpretation to the second law of thermodynamics.

Lomonosov's opinions on optical phenomena also diverged from those of the majority of his contemporaries and were also in tune with the opinions of nineteenth-century physicists. The idea that light could be disturbances propagating in an all-permeating medium, the ether, crops up as far back as the seventeenth century. In this same period a conflicting point of view, taking light to be the flux of a special kind of weightless fluid, of light particles, also appeared. After Newton, who had championed the second point of view and defended the corpuscular theory of light, the majority of physicists followed suit and the corpuscular theory prevailed; such a situation continued up to the eighteen-thirties. Only a very small number of physicists in the eighteenth century adhered to the wave theory of light. The attitude of these physicists was regarded as something of an anachronism. The opinions of Euler, who in the eighteenth century came to the defense of the wave theory and tried to elaborate it, were thought of in this way. Priestley in his book "History and Present State of Optics," published in the second half of the eighteenth century, wrote: "... no one, however, disputes the Newton theory with such assiduity and energy as the eminent mathematician Mr. Euler, who has summoned again to life and defended Huygens' hypothesis, according to which light consists of oscillations propagating from luminous bodies in a thin ether medium."[5]

This same energetic adherence to the wave theory of light which Priestley attributed to Euler could in all truth also be attributed to Lomonosov. In a number of his works, particularly in one especially devoted to optics, "A Word About the Origin of Light, Presenting a New Theory of Colors," he sharply attacks the corpuscular theory of light and defends the wave theory.

Speaking in favor of wave theory, he brings forward a number of considerations against the corpuscular theory. Some of these considerations coincide with the arguments advanced by Euler against Newton's theory in his well known "Letters to a German Princess," published after Lomonosov's death in 1767—1772. For example, Lomonosov shows that from the point of view of corpuscular theory it is incomprehensible how light beams can simultaneously penetrate a transparent body in different directions without interfering with one another. A thousand candles may be placed about a diamond, he writes, so that a thousand beams of light intersect, and not one beam will interfere with another. In Lomonosov's opinion, this fact contradicts corpuscular theory; as regards wave theory, it is self-explanatory, since waves pass in different directions across the same point in space without disturbing one another.

Approaching this problem in another, analogous case, Lomonosov presents interesting arguments: "Water waves also provide us with evidence: if, when the air is calm, we throw stones at various places on the water's surface, each one taken separately produces its own waves which travel in a straight line away from the point of impact in all directions to meet each other. They continuously now reinforce, now weaken one another, but do not cease until the applied force is blunted for other reasons."[6] If Lomonosov had dealt with his problem in greater detail and considered the case of the meeting of waves which arrive at a point in different phases, it is quite possible that he would have deduced the principle of wave interference, which was discovered by the English physicist Young at the turn of the nineteenth century.

Lomonosov formulated another interesting objection to the corpuscular theory of light. Take a grain of sand, he said, and lay it in the sun. According to Newton's theory, light particles flow into this grain. However long this grain of sand is kept in the sun, it will not glow at all if it is taken away to a dark place. The question arises: what has become of all the light particles which entered the grain? They have not been reflected from it, since black bodies absorb all the light rays which strike them. "Black materials," wrote Lomonosov, "do not ward off the rays which reach them, nor do they permit them to pass through," and he added, "Tell me, admirers and defenders of the concept of the fluid motion of matter, where in this case does the light hide itself?"[7]

This was quite an important objection to the corpuscular theory of light. It is especially interesting because of the fact that Lomonosov here touches on the phenomenon of the absorption of light. It seems that Lomonosov was interested in the absorption of light and still more in the relation between the absorptive and emissive powers of bodies. A whole series of his notes attest to this.

Lomonosov first of all emphasized that not only light but also heat rays are propagated by an incandescent body. He established that bodies differing in absorptive and reflective capacities behave differently for light and heat rays. For example, he wrote that the rays of the sun reflected from the moon and focussed with a burning lens, although "they shine quite brightly and clearly, produce no sensible warmth."[8] This he explained by the fact that light rays are reflected well from the surface of the moon, heat rays poorly.

Lomonosov also cited an experiment which he had carried out himself. He wrote: "A powerful converging mirror, covered with black varnish, produces at the focus a very strong light but little heat, clearly showing that the rotational motion of the ether in a black material has died down while the wave motion has remained unhindered."[9] Let us recall that according to Lomonosov's hypothesis light rays are waves in the ether and heat rays are the propagation of the rotational motion of its particles; consequently, he affirms that light rays are reflected well from the mirror in question while heat rays are absorbed by it.

In the history of physics the concept of thermal radiation or radiant heat is considered to have been introduced in 1777 by the Swedish scientist Scheele, who for the first time used the term "radiant heat." Scheele inferred the existence of heat rays similar to light rays and explained that a glass mirror reflects light but not heat while a metallic mirror reflects both.

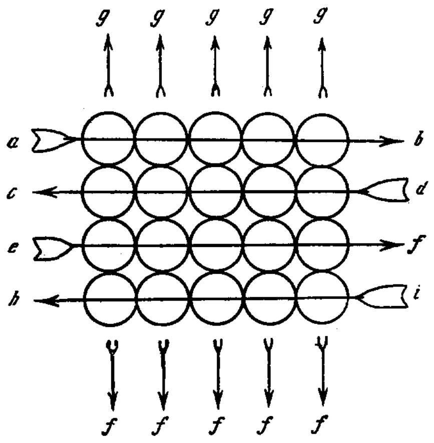
Then the Swedish scientists Pictet and Prevost, and the German astronomer Herschell took up the investigation of heat rays. They confirmed Scheele's conclusions and discovered a number of new properties of thermal radiation. However, as late as the beginning of the nineteenth century the existence of heat rays was disputed by the Englishman Leslie, who claimed that heat could not be transmitted through empty space.

Lomonosov's research and reasoning on thermal radiation presented above oblige us to acknowledge that he was among the predecessors of Scheele and other scientists who studied thermal radiation.

While engaging in optics research, Lomonosov also developed a theory of colors. This theory was of course primitive, being based on the hypothesis that three kinds of ether particles and accordingly five kinds of particles of ordinary matter, the basic elements, existed. We will not give an account of this theory here. We will only observe the interesting fact that the existence of a relation between the emissive and absorptive powers of a body followed from this theory. To be more exact, this theory implied that the spectral composition of the rays which a body can absorb and which it emits when heated are one and the same. If, for example, a body absorbs red rays, when heated it must also emit red rays. Thus a correct idea about the relation between absorptive and emissive powers, although in a primitive form, is contained in Lomonosov's theory.

In connection with Lomonosov's theory of light and colors, one other interesting fact should be noted. Lomonosov did not think that light waves were waves of compression and rarefaction of the ether medium as sound waves are of air. In the case of sound (in his opinion), such waves can occur because the air particles are located at "perceptible" distances from one another, whereas the particles of ether are in contact with each other. As a confirmation of this assumption, Lomonosov cited the incomparably greater velocity of light propagation as compared with that of sound.

Such considerations might have led to the idea that, unlike sound waves, light waves are transverse. Lomonosov actually did suggest the transverse nature of light waves, although he did not emphasize it especially. Sketching a diagram of the mechanism of wave propagation in ether, he indicates that the direction of propagation of the disturbances in the ether medium is perpendicular to these disturbances. He wrote: "Let there be motion in the ether particles in such an order that when rows ab and ef are jolted from a and e to b and f, rows cd and hi at the same time are jolted in the opposite direction, from d and i to c and h. From this must ensue the striking of particles and the motion of the neighboring ether particles in the directions f and g; and thus light flows out everywhere and can be seen from all sides"[10] (see diagram).



The idea of the transversality of light waves was expressed in the nineteenth century by Young and Fresnel and for the first time adopted to explain phenomena associated with the interference of polarized rays; Fresnel then used it to construct a wave theory of light. As we know, this idea at first encountered great opposition on the part of many physicists of that time.

Lomonosov's principal service in the investigation of electrical phenomena lies in his development of a theory of the formation of atmospheric electricity. In this theory he expressed a correct hypothesis in very general terms (as in other cases we have mentioned) as to the mechanism of the formation of atmospheric electricity. This idea was again taken up and developed considerably later, in the second half of the nineteenth century. But Lomonosov did not limit his investigation to atmospheric electricity. An attempt to outline a general theory of electrical phenomena is also contained in his works and notes.

Lomonosov saw the essence of electrical phenomena in the motion of the same ether by whose motion he explained optical phenomena. In his opinion, electrical phenomena are caused by the rotational motion of ether particles. Motions of this kind are easily excited by friction, and are quickly transmitted within the "perceptible bodies" by ether particles contained in the pores of these bodies. If motions are transmitted to the ether surrounding ordinary bodies, phenomena should occur (in accordance with Lomonosov's optical views) involving the liberation of heat and the emission of light. For example, a spark may leap, a glow may be observed in a "sphere from which the air has been exhausted," etc. "The electrical force acts by this means, and can be clearly represented, interpreted and demonstrated without recourse to miraculous materials incomprehensibly running in and out without any cause in contrary motion,"[11] Lomonosov observed.

Lomonosov's theory of electricity was probably the first theory in which electrical phenomena were interpreted as the motion of ether. Before this, the view that electrical phenomena were due to the outflow of a special sort of electrical fluid from electrified bodies prevailed. Franklin approached the problem of the nature of electricity somewhat differently. He assumed that electrical phenomena can be explained if we admit the existence of an electrical fluid between whose particles, as well as between them and the particles of matter, forces of attraction and repulsion act. However Franklin at the same time assumed that the electrified bodies are surrounded by a certain "electrical atmosphere."

Euler, as well as Lomonosov, attempted to explain electrical phenomena by the action of the ether; he assumed that the density of the ether in an electrified body differs from that in the surrounding space. If the density of the ether in the body exceeds that in the surrounding space, the body is positively electrified, if it is lower, negatively.

During Lomonosov's lifetime, however, there appeared a new opinion on electrical phenomena based on the admission of forces acting at a distance between particles of the electrical matter and also between the latter and particles of ponderable bodies. The Petersburg academician Epinus began this trend, and after Coulomb's Law was established this view became generally accepted. It persisted up to the works of Maxwell who, following the ideas of Faraday, again revived the notion that the essence of electrical phenomena consists in the motion of the ether.

From what has been said above, we may indeed consider Lomonosov as the initiator of that very trend in the study of electricity which in the second half of the nineteenth century led to the creation of electromagnetic field theory; in this respect he may be considered the predecessor of Faraday and Maxwell. Moreover, it must be especially emphasized that Lomonosov also suggested the unity of optical and electrical phenomena. In his opinion, both these and other phenomena are the result of the motion of one and the same ether. In this respect also we must consider Lomonosov as the predecessor of Maxwell, who elaborated the idea of the electromagnetic nature of light.

Special significance attaches to the fact that Lomonosov's idea of the indivisible nature of electrical and optical phenomena was not a mere "speculation." We know that Lomonosov arrived at this idea as the result of a whole series of experiments which he conducted himself.

In Lomonosov's notes many records can be found of his observations or directions for proposed experiments aimed at studying the relationship between electrical and optical phenomena. For example, Lomonosov intended to "sample the electric force at the focus of a burning glass or mirror; test whether the colors of the rainbow are brighter in hot or cold water or the converse. The same in electrified and plain water." A very interesting experiment which Lomonosov intended to carry out was directed at clarifying the relation between electricity and light; it consisted in verifying whether "a ray of light will be refracted differently in electrified glass and water." A similar experiment, as we know, was performed in 1875 by Kerr, who demonstrated the phenomenon of double refraction in an electric field.

It was characteristic of Lomonosov not only to attempt to establish a connection between electrical and optical phenomena, but also to investigate the relations between various kinds of physical phenomena and between physical and chemical phenomena.

Optical and electrical experiments must, he thought, be performed to examine the properties not only of light and electricity, but also of the bodies themselves: their molecular structure, chemical composition, etc. On the other hand, chemical research must help in clarifying the nature of light and electricity. In general, experimental research should be set up in such a way that the study of some phenomena is associated with the study of others.

We find in Lomonosov's plans for experimental investigations a large number of proposed experiments of this kind. For example: "Will electrified tin melt at a lower heat?", "to study the refraction of solar rays in solutions as compared with water," "does electric force have any effect on the dissolving of salts?", "what will be the color of electric sparks and flames induced in salt solutions and in saline liquids?", "to observe whether electric force aids or hinders crystallization," "does electric force accelerate precipitation?", etc.

Such experiments were neither typical nor generally accepted at the time when Lomonosov lived, but they became so for nineteenth-century science, when the new problem of investigating the relations between isolated physical phenomena presented itself to physicists.

One of the basic principles governing Lomonsov's research in physics and chemistry was the principle that matter and motion can neither be created nor destroyed. Lomonosov was the first to formulate this general principle as a principle of the conservation of the basic quantities in nature. Here, from a letter to Euler, is the well-known formulation: "All changes met with in nature occur in such a way that if something is added to one thing, it is taken away from another. Thus, as much matter is added to one body as is lost by another body; as many hours as I spend in sleep I subtract from wakefulness, etc. Since this is a universal law of nature, it also extends to the laws of motion: a body which by its impact excites another body into motion loses as much of its own motion as it communicates to the other body set in motion by it."[12]

This general thesis as applied to matter and motion was not new. The idea of the conservation of matter was conceived in ancient Greece, and was accepted by the majority of natural scientists and philosophers of the seventeenth and eighteenth centuries. It was closely connected with the doctrine of atoms, according to which atoms neither disappear nor are created from anything, all changes in nature occurring as the result of their uniting and separating.

However, in spite of the fact that this idea was rather widespread, it had not been experimentally verified, nor was it stated in the form of a concrete natural law. Besides, it was not clear how the concept of weightless materials fitted in with the general idea that matter could neither be created nor destroyed. Here Lomonosov took a decisive step in the direction of establishing a natural law—the law of the conservation of substance, which is a concrete expression of the general principle of conservation of matter.

In 1673 the English scientist Robert Boyle reported his experiments determining the ponderability of fire, which he considered as a special substance responsible for the warmth of a body. He heated a sealed retort containing lead, weighed the lead before and after heating, and discovered that the weight of the lead had increased. Hence he drew the conclusion that during the roasting process the fire substance had penetrated the walls of the retort and added itself to the lead, transforming it into slag and increasing its weight. When the phlogiston theory was developed subsequently, it was necessary to explain the results of Boyle's experiment by saying that the phlogiston, which had negative weight, had come out of the lead slag during the heating.

In his work "Reflections on the Cause of Heat and Cold," Lomonosov had already disagreed with Boyle's explanation of the increase in weight of the roasted metal. He suggested that such an increase in weight might be explained as the combination of the metal with the air enclosed in the retort. He wrote that all Boyle's experiments "on increase in weight under the action of fire simply mean that either the parts of the flame heating the body or the parts of the air passing over the roasting body while it is being heated possess weight."[13]

In 1756 Lomonosov repeated Boyle's experiment. He weighed, not the metal before and after heating, but the retort which contained the metal during the roasting. He found that the total weight of retort and metal did not change in roasting. In the account of his activity during this year he wrote: "Among various chemical experiments recorded on 13 sheets are experiments made in tightly sealed glass containers with the aim of discovering whether the weight of the metal increases from heat alone; it was found from these experiments that the opinion of the famous Robert Boyle is false, for without the admission of external air the weight of the burned metal remains the same."[14]

This experiment showed that the total weight of two substances before and after a chemical reaction does not change. Thus the law of the conservation of weight in chemical reactions, which was the first concrete expression of the general law of conservation of matter, was established and formulated by Lomonosov as a universal natural law.

In 1774 Lavoisier published a work in which he described experiments similar to Lomonosov's experiments with the roasting of metal. Like Lomonosov, he also found that the total weight of retort and metal before and after heating did not change. In addition, he added a new step: not only did he weigh the retort and metal before and after roasting, but he determined the change in weight of the metal and air separately. He found that the decrease of air in the retort was equal to the increase in weight of the metal after roasting. Hence he concluded that during roasting the metal combined with air in the retort.

Initially Lavoisier considered the results of these experiments only as evidence of the falsity of the phlogiston theory. Not until 1789 did he suggest a law of conservation of weight in chemical reactions, interpreting it as an expression of the principle of conservation of matter.

Lomonosov did not publish the results of his experiments with the roasting of metal, and priority in the discovery of the law of conservation of material was for a long time assigned to Lavoisier, who unlike Lomonosov got his research into print (it was well known in Europe).

Lomonosov's records, in which the results of his experiments were reported, were published for the first time in 1865 by Bilyarskii. Still more time passed before they attracted attention and Lomonosov's priority in the discovery of the law of conservation of substance was established. The question naturally arises, why did Lomonosov not publish his results? This cannot be explained by saying that he was afraid of infringing upon Boyle's authority. Lomonosov, who already at that time (1754) enjoyed great prestige at the Petersburg Academy of Sciences and had not feared coming out against the views of the great Newton even on the nature of light, would scarcely have been afraid of coming out against Boyle's incorrect conclusions. What apparently happened was that Lomonosov either did not attach major importance to his experiment or found it difficult to interpret. This opinion is confirmed by the fact that, when at the end of his life compiling the "Review of the Most Important Discoveries by Which Mikhaĭlo Lomonosov Has Tried to Enrich the Natural Sciences,"[15] he does not mention at all the investigations of metals which led to the establishment of the law of conservation of weight in chemical reactions.

Why is it that Lomonosov could not attach major importance to these experiments for the establishment of the law of conservation of matter? It is entirely possible that he may have doubted whether the conservation of the total weight of substances in chemical reactions was indeed an expression of this law. In order to conclude that this was so, it was necessary to assume that the weight of the body determines the quantity of matter in it as Newton did (after establishing that the force is proportional to the mass and assuming the mass to be a measure of the quantity of matter).

Being an opponent of the theory of action at a distance, Lomonosov did not consider this thesis indisputable. Under the assumption that the force of gravity is explained by the action of a "gravitational matter," possibly ether, he was forced to conclude that the weight of a body is proportional not to the quantity of matter contained in its particles but rather to the surface of these particles on which the gravitational matter acts. It is known that Lomonosov pondered this problem. He wrote in a letter to Euler in 1748: "When trying to establish certainty in the principles of chemistry and in all the widely prevailing ideas from the region deeply plumbed by physics, my way is blocked by a generally accepted opinion, taken as axiomatic by the majority, that the density of the connected material of bodies is proportional to their weight. I acknowledge without hesitation that this is correct for homogeneous bodies.... I give my consent when I read the words of that outstanding man, Isaac Newton, that 'Thus air of a double density, in a double space, is quadruple in quantity; in a triple space, sextuple in quantity. The same thing is to be understood of snow, and fine dust or powder, that are condensed by compression or liquefaction; ....' ("The Mathematical Principles of Natural Philosophy," Definition 1). But I cannot agree with the general conclusion at the end that "mass is known by the weight of each body."[16]

Considerably later in the study "Relation of the Quantity of Matter to Weight," Lomonosov again expresses himself on the same note. In this work he subscribes to the hypothesis of gravitational matter, from which it follows that "the specific weight of bodies varies in proportion to the surface with its impenetrable corpuscles which opposes the gravitational fluid."[17] As a consequence, he maintains, "the quantity of matter will not be proportional to the weight."[18] Finally, there is the testimony of Euler's pupil Rumovskii as to Lomonosov's opinions on this matter. Rumovskii in a letter to Euler wrote that Lomonosov argued as if "the weight of bodies is not proportional to the quantity of matter," and that he found the so-called circulus error in the arguments of Newton and other physicists "when they want to prove that the weight of bodies is proportional to the amount of material."[19]

Taking into account the above statements, we can conclude that, according to Lomonosov, the law of conservation of weight cannot be an expression of the general law of conservation of matter which he formulated. Moreover, there must exist a certain difficulty in explaining the fact, which he also established, that the total weight of substance is conserved in chemical reactions. It is quite possible that doubts of this sort prevented him from publishing his law.

The general law of conservation established by Lomonosov includes within itself the law of conservation of motion. The situation in the science of that time with regard to the conservation of motion was somewhat different from that with regard to the conservation of matter. Two different, quantitative formulations of this law had already been proposed in the seventeenth century, the law of conservation of momentum suggested by Descartes, and the law of conservation of live force (vis viva) established by Leibniz.

Descartes was guided by the general idea that matter and its motion can neither be created nor destroyed. He assumed that the total amount of motion of the particles participating in each process in nature remains constant. He adopted for momentum a quantity equal to the product of the mass by the absolute value of the velocity (speaking in modern terms).

It was soon found necessary to correct Descartes' conservation law: momentum became the product of the mass by a velocity whose direction was taken into account, i.e., velocity was considered as a vector quantity. But in this form the law of the conservation of momentum could no longer have such fundamental significance as Descartes ascribed to it. For example, two bodies moving towards one another with any velocity have a total momentum equal to zero, as is the case with a resting body. However, at that time this problem was not sufficiently clear, and a number of scientists continued to adhere to Descartes' point of view.

Somewhat later Leibniz proposed another conservation law, the law of conservation of live force. According to this law the total live force (here also was included the so-called dead force, in modern language the potential energy) is conserved in all natural processes. A quite heated discussion developed between Descartes' followers and Leibniz and his followers about what is conserved in nature—momentum or live force.

In Lomonosov's time this question was still unresolved and the discussion continued, although slowly losing its edge. Both conservation laws were already widely employed in mechanics; they gradually lost their major significance as universal laws and took on the character of purely mechanics theorems. It must be added that Newton did not acknowledge the operation of any law of conservation of motion. In his "Opticks" he wrote: "The variety of motions which we find in the world is constantly decreasing, and must be conserved and replenished by the intervention of active sources —such is the reason for gravitation, by whose aid the planets and comets retain their orbital motions, and bodies obtain great motion by falling."[20] It is also known that Leibniz carried on a rather long polemic with Newton's student Clarke on the conservation of motion in nature. To rebut Leibniz Clarke denied the operation of the law of conservation of live forces and assumed that God must from time to time replenish motion in nature, so to speak wind "the world's clocks."[21]

After Descartes and Leibniz, Lomonosov again came out for recognizing the general principle of conservation of motion in nature as a universal law operating in all natural phenomena. Not restricting himself to this, he applied the principle widely in his own research. Thus, assuming that heat is motion, he made use of the principle of indestructability of motion: the mechanical motion of visible bodies disappears in friction; but since motion cannot be destroyed, it must be transformed into the motion of invisible particles or atoms—so he argued.

Lomonosov directly enlisted the thesis of conservation of motion to explain the transfer of heat from a heated to a cold body. He wrote: "If a warmer body A is in contact with a less warm body B, the particles of the body A at the points of contact, rotating more rapidly than the neighboring particles of body B, with their faster rotation accelerate the rotational motion of the particles of body B, i.e., transmit a part of their action to them; as much motion leaves the former as is added to the latter, i.e., when the particles of body A accelerate the rotational motion of the particles of body B, they slow down their own motion."[22]

Lomonosov also uses his thesis of conservation of motion in his objection to admitting the existence of forces acting at a distance. In his opinion, if two bodies initially at rest go into motion merely as a result of forces acting at a distance and nothing happens in the surrounding space, this means that motion has originated out of nothing. This is impossible, since it contradicts the law of conservation of motion in nature.

Thus, applying the general principle of conservation of motion to various physical processes, in essence already using it as a heuristic principle, Lomonosov goes further than Descartes or Leibniz, and takes a new step towards discovering the law of conservation and transformation of energy.

It is natural that Lomonosov could not overlook the problem of the measure of motion. He indicated that this problem was not solved. He wrote: "The very first principles of mechanics, thereby also of physics, are still controversial, and ... the most outstanding scientists of our century cannot come to an agreement about them. A very obvious example of this is the measure of the forces of motion, which some take in a single, others in a two-fold proportion to velocity."[23]

How Lomonosov resolved this problem himself can

only be guessed at. In a letter to Euler, Rumovskii reported on Lomonosov's reasoning on this matter: "Mr. he intends to overthrow everything discovered up to this time, because he argues ... that momentum is not proportional to the mass multiplied by the square of the velocity."[24] In another letter he reported that Lomonosov, in order to solve the problem of the measure of motion, demonstrated an experiment "performed using a small wheel placed in a channel through which water flowed."[25]

One can show from these statements that, on the subject of the measure of motion, Lomonosov joined Descartes in assuming that in nature momentum is conserved. However, this would be a hasty conclusion. Lomonosov's opinion seems to have been more profound and original. When determining the measure of motion of a macroscopic body, he probably considered it necessary to take into account not only this body's mass and velocity but also that of the ether set into motion by this body (since it is surrounded and permeated by ether). Speaking along these lines in "Relation of the Quantity of Matter to Weight," he writes: "Actually, if we assume a dense ether surrounding all bodies and the smallest particles of bodies, it is in no way possible to decide and determine exactly how much resistance must be attributed to the matter of the moving body itself and how much to the resisting ether."[26]

These views and arguments of Lomonosov's are extremely interesting, for here he anticipates a whole series of ideas developed at the turn of the twentieth century in connection with the electron theory.

In 1881 J. J. Thomson investigated the motion of a charged sphere. He showed that in the case of velocities considerably smaller than the velocity of light the mass of this sphere effectively increases by an amount proportional to e^2/r because of the magnetic field created by its motion (e is the charge and r the radius of the sphere). J. J. Thomson and other scientists naturally interpreted this increase in the inertia of the sphere as the result of the fact that the moving sphere caused the surrounding ether to move, this motion manifesting itself as the magnetic field created by the charge located on the sphere.

After the discovery of the electron and the establishment of the dependence of its mass on velocity, there arose the concepts of an electromagnetic mass and an electromagnetic quantity of motion. These concepts were at first interpreted as the result of the fact that in motion, the inertia of electric charges (of which every substance was made up) was the result not only of the inertia of the ordinary mass of the charges themselves (i.e., of mass in the Newtonian sense as a quantity of matter) but also of the inertia of the surrounding ether which was set into motion by the moving charges associated with the substance.

Thus Lomonosov's idea that the inertia of a body is determined not only by the inertia of the particles making up the body but also by the inertia of the ether a new form at the beginning of our century, that is, almost 150 years after he first suggested it.

Besides the studies, theories, and ideas set forth above, whose theses and hypotheses came to be a basis for the subsequent development of physics, a whole series of Lomonosov's scientific achievements relating to more restricted problems of physics and related sciences could be cited. We know, for example, that Lomonosov proposed quite a few designs for various physics, meteorological, and other types of apparatus. Many such devices began to find employment in scientific research considerably later, in the nineteenth and even twentieth centuries.

We will not in this article deal with that aspect of his activity, but enough has been said to correctly evaluate the genius of M. V. Lomonosov, the first Russian natural scientist and the founder of Russian science, who in his scientific investigations was far in advance of his own time and foresaw the path of development which physical science followed many years afterwards.

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[24] P. P. Pekarskii, Istoriya Imperatorskoĭ Akademii nauk v Peterburge (History of the Imperial Academy of Sciences in Petersburg), Vol. II, St. Petersburg, 1873, p. 600.

[25] Ibid., p. 601.

[26] M. V. Lomonosov, Complete Works, Moscow, Acad. Sci. Press, Vol. III, p. 353.

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