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LIFE AND SCIENTIFIC ACTIVITY OF PETR NIKOLAEVICH LEBEDEV

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P. N. LEBEDEV, one of the outstanding physicists of the end of the 19th and beginning of the 20th century, occupies a special place in the history of Russian physics. He was not only a brilliant experimenter, one who made our country famous with work of astounding subtlety and perfection, but also a leader of broadly conceived collective research and the creator of the first Russian school of physicists.

Lebedev lived a short but bright life, filled with labor and daring. His creative career covered more than 30 years, which can be divided into three periods: first years of study and the early still unsuccessful but useful and imaginative work, ending with his first scientific papers; then 12 years of intense work in a well planned direction; and finally 10 years of equally intense work, but already as a recognized major scientist, directing the first large scientific staff in Russia.

Lebedev was born in Moscow on 8 March 1866 in a comfortable merchant family that was very enlightened for that time. Lebedev's father was absorbed in commercial activity. There were also two daughters, and Lebedev, as the only son, was in his father's opinion to be his successor. To this end, he was sent to the commercial division of the Petropavlovsk German school in Lefertovo. The instruction in that school was in German, and Lebedev has learned it so thoroughly that he was equally fluent in it as in Russian. This subsequently greatly facilitated his work in the Strasbourg and Berlin Universities.

Already at the age 15—16, under the influence of a close friend of the family, Lebedev revealed a tendency to scientific discoveries and research: He carried out many experiments, principally with electricity. His bent and views have reached us in the form of notes in a scrap book, which begins with a number of questions. The question "Your calling" is answered by the young Lebedev "to be a researcher or a discoverer."

At first the father would not hear of a scientific career for his son, but he had to give in. He was transferred to the sixth year of a private realgymnasium. After finishing that school at the age of 18, he entered the Technical School (now the Bauman Moscow Higher Technical School). He was unable to enter the university, which was more appropriate for his scientific bent, for lack of knowledge of Latin.

The program of the Technical School provided learning of pipefitting and lathe operation, drafting, and design, and this was very helpful to him later in the creation of precise physical instruments.

The completion of the required program consumed much time. In spite of this, Lebedev had time to read scientific literature and soon began to attempt scientific and technical research, which, however, he did not complete. Usually a new idea, which turned out to be more attractive, crowded out the earlier one, and lack of experience and knowledge also came into play. Quite a time elapsed before Lebedev acquired the rare patience and the unusual persistence in overcoming seemingly unsurmountable difficulties, which were so characteristic of the later period of his life.

After spending three years at the Technical School, Lebedev went to Strasbourg in the fall of 1887 to continue his education.

At the Strasbourg University the Physics Department was headed at that time by Professor August Kundt. A most skillful experimental physicist, known for many discoveries in the field of acoustics and optics, Kundt was one of those scientists who gather

scientific staffs. According to his plans and under his guidance, there was constructed in Strasbourg a Physics Institute which was exceptional for that time, and which attracted for study and advancement many physicists from all parts of Germany and other countries. Studying together with Lebedev in Strasbourg were at that time Wiener, Rubens, Paschen, and among the Russians V. A. Ul'yanin, S. Ya. Tereshin, and B. B. Golitsyn. Close and friendly relations were established between the latter and Lebedev.

Professor Kundt and Lebedev, in spite of the difference in age, had much in common: a passionate attraction to science, great talent as experimenters, and an abundance of new ideas. Kundt soon recognized and was greatly impressed by Lebedev's qualities, and singled him out among his students; providing him with opportunities for independent work. Lebedev thought himself happy. After a year's stay in Kundt's laboratory he wrote his mother: "With each day I become more and more in love with physics... Soon, it seems to me, I shall lose my human image, I already can no longer understand how one can live without physics."

In the same 1888, Kundt moved to Berlin to occupy Helmholz's chair, and Lebedev moved with him. Some of Lebedev's ideas had so attracted Kundt, that he himself took part in the experiments, but the overabundance of ideas clearly interfered with Lebedev's work. Ultimately Kundt began to worry about the fate of his favorite student. The time came to complete the doctoral dissertation and to pass the doctoral examinations. In Berlin, again owing to the lack of a knowledge of Latin, this was impossible for Lebedev. At Kundt's advice he returned to Strasbourg. There Kundt's place was occupied by a good but all-around physicist, Friedrich Kohlrausch, who agreed with the dissertation topic proposed by Lebedev: "Investigation of the Dielectric Constant of Vapors."

After two years of persistent labor, Lebedev completed his first scientific work "On the Measurement of Dielectric Constants of Vapors and on the Mossoti-Clausius Theory of Dielectrics," defended it, and received the degree of Doctor of Philosophy from the Strasbourg University. The main conclusion of the work was as follows: Faraday's hypothesis that molecules are electrically conducting bodies, or that molecules have an exceedingly high dielectric constant, lead to no contradictions whatever with the observed phenomena.

This result was important for Lebedev, since it showed that when an electric field acts on a molecule the latter can be regarded as a resonator of definite dimensions, and nothing could agree better with the thought, which occurred to him already in 1890, that intermolecular forces have a resonant character.

During the last year of his stay in Strasbourg, Lebedev was engaged to a considerable degree in Maxwell's theory. It followed from Maxwell's theory that if the molecule is regarded as an electric resonator, then the electromagnetic field of the light wave should exert mechanical action on it. This idea was first applied in Lebedev's theoretical paper "On the Repulsion Force of Radiating Bodies," in which the light pressure was assumed to be the cause of the development of comet tails.

Lebedev regarded his calculations only as qualitative, since the molecule dimensions are small compared with the wavelengths of light, and the interaction should depend on the specific properties of the molecules. He arrived at the conclusion that in principle the interaction of molecules can be likened to a complicated mutual interaction between resonators.

Before leaving Strasbourg, during Kohlrausch's last summer colloquium on 30 July 1891, Lebedev presented a concluding report on the nature of molecular forces. The paper took two hours to deliver and was accompanied by an experiment, which, as Lebedev wrote, "succeeded as they seldom succeed." However, in concluding the session, Kohlrausch, while pointing the fruitfulness of the communicated ideas, warned that the conclusions must be drawn with great caution and that they must first of all be confirmed by experiment.

Thus, Lebedev's program of scientific activity was predetermined in Strasbourg. It was there that his research on the ponderomotive action of incident waves on resonators and his work on light pressure originated.

Before we proceed to describe the Moscow period of Lebedev's life, in which he did his basic work, we must deviate slightly and, interrupting the chronological description of the events and Lebedev's scientific activity, dwell on his character as a scientist.

Lebedev loved to express his thoughts in letters and in diaries. They revealed a high degree of emotionality and absorption in new ideas, science, and art. He vividly responded to everything that was new, he was attracted to experiments which were not trivial and far from safe: he ascended in a balloon, experimented with x rays immediately after their discovery; his experiments and demonstrations of x rays were extremely successful, but he had to pay for this enthusiasm with a burnt face. Finally, as he grew older, his character changed, the buoyancy and instability decreased, experience and persistence increased, but to his last days he remained a scientist passionately devoted to science, boldly undertaking experiments of any complexity.

The extent to which Lebedev selflessly was attracted to a scientific idea, even in the last years of his life, can be judged at least from the case of his encounter with Professor Wolf.

In the spring of 1909, overtired after prolonged scientific work on the pressure of light on gases, Lebedev went to Switzerland for a vacation, but first stopped in Heidelberg, to see a famous heart special-

ist, Professor Erb, whose advice Lebedev greatly valued. In Heidelberg he met the astronomer Wolfe and told him of his lack of success in his work. Wolf, now knowing of Lebedev's sickness, persistently begged him not to discard the work, since this work is very important for astronomy and it is beyond his own power to carry it out alone. Returning to his quarters, Lebedev thought out a new variant of experiments. In the morning, instead of going to Switzerland, he was already on the train to Moscow. There, in spite of his sickness, Lebedev continued to work intensely all summer and fall, and in December 1909 he delivered a paper at a congress of experimental naturalists and medical doctors.

An experimenter of amazing inventiveness, Lebedev did not like mathematics. This was the effect of Kundt's school. Without resorting to theoretical calculations, Lebedev, however, had the knack of grasping the principal point in the phenomenon and, simplifying the problem to the utmost, was able to solve it with the aid of his Lebedev arithmetic, which subsequently became famous. Persons who knew Lebedev personally remembered his jokes on his closest friend, the physicist Professor A. A. Eichenwald, who always warned him of various difficulties, which Lebedev overcame by his unsurpassed experimental mastery.

Using skill acquired at the technical school, Lebedev not only designed but frequently constructed the apparatus himself. He was a skillful lathe operator and carpenter. Only later on he found in this respect a devoted and clever assistant in the person of the mechanic A. I. Akulov.

Lebedev's speech was exceedingly picturesque. Strict with himself, he was strict with those surrounding him. A high degree of circumlocution frequently evoked very sharp rebukes.

Lebedev was not only a scientist but also a man of many interests. He was attracted by sport - rowing, horseback riding, mountain climbing—he loved music and the theater, and was a fine connoisseur of both. In his later years, as professor of the Moscow University, he was acquainted with many actors of the Bolshoi and Art Theaters, particularly V. I. Kachalov. The actors of the Art Theater took Lebedev's opinion very seriously, and V. I. Kachalov used to drop in to his laboratory specially to become acquainted with habits and mannerisms of scientists.

Lebedev usually spent his summer vacations abroad. He visited laboratories and took part in conferences. Lebedev's name was known in all the European countries.

He was in the habit of writing down his ideas and describing his experiments with great detail in scientific diaries reminescent of bookkeeping ledgers. From these it was possible to trace exactly all stages, failures and successes, of his scientific creativity. The final versions of Lebedev's articles, however, are distinguished for brevity. "Write briefly," he used to say, "nobody reads long articles." This advice is even more to the point in our time.

After the discovery of light pressure, the foreign scientific journals very gladly printed papers by Lebedev and his students. Most of Lebedev's papers were published in leading journals in several languages - Russian, German, English, and others. Thus, Lebedev's ideas became immediately accessible to a wide circle of scientists.

But let us return to the main topic of our article.

After the concluding paper at Kohlrausch's colloquium in Strasbourg, where Lebedev formulated his concepts regarding the character of intermolecular interactions, he returned in August 1891 to Moscow, where the Physics Department was headed at that time by Professor A. G. Stoletov. Stoletov offered Lebedev a position of assistant. This started the second period of Lebedev's scientific activity.

The conditions for experimental work at Moscow University were at that time exceedingly unsatisfactory. The Physics Institute was located in a small two-story house in the courtyard of the old building of the University on Mokhova Street. Located in the second story of this house was a physical laboratory for the students, and the research work was carried out in an adjacent room, separated only by a light curtain. To equip this room, Lebedev bought lathes and pipefitting machinery for 300 rubles, thereby completely upsetting Prof. Stoletov. In this small room next to the physical laboratory Lebedev carried out three investigations on the ponderomotive action of waves on a resonator, work on birefringence of electromagnetic waves, and the first work on light pressure on solids.

When Lebedev started to attract the most advanced students to scientific work, they already had to work in the general laboratory, during hours when there were no students' laboratory assignments; much later some of them were allowed to work in the room where Professor A. P. Sokolov had a special laboratory.

Lebedev and B. B. Golitsyn attempted to transfer to Moscow the scientific atmosphere of Strasbourg. They delivered papers at the Society of the Lovers of Natural Science, and also public lectures. Following a program which became crystallized in Strasbourg, and desiring to confirm experimentally his views on the character of intermolecular interactions, Lebedev decided to investigate the ponderomotive action of waves on a resonator acting as a schematized molecule.

After eight years of work, in 1899, Lebedev defended at the Physical-mathematical Faculty a dissertation for the degree of Master of Physics, "Experimental Investigation of the Ponderomotive Action of Waves on Resonators." The dissertation contained three sections devoted to electromagnetic resonators, hydrodynamic resonators, and acoustic resonators.

The main result of the work was the establishment of the following resonator properties: 1) The mechanical action of the exciting wave on the resonator is proportional to the incident energy and depends on the ratio of the number of oscillations of the source and the resonator. 2) If the resonator is tuned to a higher frequency than the exciting source of oscillations, it is attracted by the latter, and if tuned lower it is repelled.

The important result of the work was the establishment of the identity of the laws of ponderomotive action for all three investigated types of oscillations, from which it followed that the intermolecular interaction forces could have a nature other than electromagnetic. The Department took into account the fact that Lebedev already had a doctor's degree from the Strasbourg University. It relieved him of the duty of taking the master's examinations, and for the work performed it awarded the 33-year old Lebedev the degree of Doctor of Physical-mathematical Sciences. The decision of the Faculty was all the more natural, since during the time of preparing for the doctoral dissertation Lebedev performed exceedingly subtle research aimed at generating short electromagnetic waves.

In an article published in 1895, "Birefringence of Rays of Electric Force," he describes a method of obtaining electromagnetic waves of only 6 mm length, i.e., shorter by a factor 100 than those obtained by Herz, and observed their birefringence when passing through a crystal of rhombic sulfur. In this work, Lebedev attained a record of bringing together the wavelengths of electromagnetic oscillations and those of ordinary sources of light. Soon Lebedev's work became very widely known. The well known Italian physicist Righi, who was working on the generation of short electromagnetic waves, demonstrated Lebedev's instruments at the International Conference of Physicsts in Bologna. Lebedev's electromagnetic waves remained for a long time the shortest ones; a description of their generation became part of all textbooks of physics.

Upon receiving his doctorate, Lebedev was appointed professor at the Moscow University and proceded to the main labor of his life - the investigation of the magnitude of light pressure. An elementary calculation has shown that the pressure of light on gas molecules is too small to be observed in practice. Therefore he chose as his first task to investigate the pressure on solids. Such experiments were made before, but the radiometric forces and the convection forces that were produced in the previously constructed instrument greatly exceeded the light-pressure forces. Lebedev's experiments were made in a variety of variants. He had to work much towards increasing the vacuum inside the vessel in which he placed the vanes that were rotated under the influence of the light. The latest variant of the instrument is very simple in appearance. But this elegant simplicity hides subtle methods of separating the above mentioned competing forces.

Lebedev's experiments on light pressure won him world fame. He lectured with great success first in Lausanne, then in 1900 at the International Conference of Physicists in Paris. Concerning this work, the outstanding British physicist Kelvin told K. A. Timiryazev: "All my life I argued with Maxwell without admitting the existence of his light pressure, and now your Lebedev forced me to capitulate before his experiments."

Lebedev's work was awarded a prize by the Academy of Sciences. It later served as the reason for his selection as a corresponding member of the Academy.

The next natural step was to determine the pressure of light on gases. This work consumed much time and lasted several years. Lebedev constructed approximately twenty models of different instruments, gradually going over from one method to another. Finally, in 1910, his research was completed.

The idea of Lebedev's instrument was to have the light pressure produce rotation of gas placed in a box divided into illuminated and unilluminated sections. The motion of the gas was revealed by its pressure on a light-weight piston placed in the darkened section of the box. To prevent uneven heating and the resultant convection currents, hydrogen was mixed with the gas to increase the thermal conductivity.

Lebedev's work caused admiration in the scientific world. The British Royal Society selected him an honorary member.

His contemporaries who observed his work, fully appreciated his experimenter's talent. Thus, for example, Willy Wien said that "Lebedev mastered the art of experimentation to possibly the highest degree than any one else in our time."

Lebedev's name is dear to us, however, not only as that of an outstanding Russian scientist and an unsurpassed experimenter on phenomena which at that time could not be tackled by ordinary physicists. He has earned a place forever in the history of Russian physics as the creator of the first scientific school in Russia.

Already in the first years of his stay in Moscow, Lebedev started to attract the most successful students to scientific work. However, the growth of his school was hindered by the lack of a building. There could be no talk of accommodating a large staff in one room and in the physical laboratory of the old building of the Physics Institute. Therefore, until 1904, only 4—6 persons worked with Lebedev. The situation changed radically in 1904, after the building of the Physics Institute was constructed and outfitted under the direction and persistent efforts of N. A. Umov. There, Lebedev obtained for his scientific laboratory a lower subbasement, convenient for the installation of sensi-

tive instruments, and two large rooms on the second floor for personal work, altogether more than 400 square meters. The largest room of the lowest floor was made into a machine shop, in which several specializing students worked constantly. To be invited to Lebedev's group, which was considered a great honor, it was necessary to complete the program of the general practical course and to pass successfully an examination in the general physics course. Third or even second-year students could join the specialists' group. The number of specialists increased rapidly. By 1910 it reached 30. Among Lebedev's first co-workers were P. P. Lazarev, T. P. Kravets, A. K. Timiryazev, V. D. Zernov, N. K. Kaptsov, V. K. Arkad'ev, A. B. Mlodzeevskiĭ, V. I. Romanov, N. K. Shadro, and others; they were later joined by a large number of younger ones, K. A. Leont'ev, S. I. Vavilov, S. N. Rzhevkin, B. V. Il'in, and others. Because of continuously failing health, guidance of the new co-workers was delegated by Lebedev to his oldest student, then lecturer and subsequently academician, P. P. Lazarev. The developing new school adopted the spirit and traditions of scientific work established by P. N. Lebedev.

The Lebedev school was unique. There were no special machine shops at the University, therefore each specialist had to construct the equipment with his own hands. To learn carpentry and machine shop practice, the specialist was first sent for one or two months to a machine shop engaged in constructing physical apparatus for schools.

For the selection of a topic, Lebedev considered it essential to formulate the task of the work with utmost clarity and to present a complete and fully realistic plan for its performance.

He attached great significance to the study of modern scientific literature. He himself presented a course on modern problems of physics, which was highly successful. In each lecture, Lebedev reported on three or four of the most interesting recent published papers. Serving the same purpose was a colloquium organized by Lebedev, but here the participants were already the specializing students. Of course, as is the case even now, volunteer lecturers were difficult to find: usually it turned out that on the morning of the day of the colloquium Lebedev handed the first encountered student, a book, and said: "Today you deliver the report on this article."

Original papers were delivered by the students after numerous revisions. Lebedev submitted his students' papers to foreign journals and translated them himself.

He was not fond of courses in general physics, and his lectures were not easily understood. On the other hand, he did not skimp on time to guide his students. Making the rounds of the laboratory took a very long time. When Lebedev was given an apartment in the new building of the Physics Institute, the sessions with the students frequently lasted long past midnight. When going abroad, Lebedev left most detailed instructions on what to do and how, but always worried about the work and en route wrote long letters to the pupils he left behind.

The topics assigned by Lebedev were concentrated around the main direction which he himself followed. He left for himself the most difficult problems, leaving the rest to the students. This is how P. B. Leĭberg's work on acoustic resonators and the work of A. R. Kolli and V. I. Romanov on the dispersion of electromagnetic waves came into being.

The analogy between light pressure and sound pressure was investigated by N. A. Kaptsov and V. Ya. Al'tberg. A new method for measuring sound force by determining its pressure is described in the dissertation of V. D. Zernov. The investigations of processes in rarefied gases were the starting point of research by A. K. Timiryazev and P. P. Lazarev.

Lebedev's optical investigations led him to the study of spectral analysis in a wide range of frequencies; this gave rise to research by T. P. Kravets and K. P. Yakovlev.

It is impossible to list in a brief communication all of Lebedev's students and their researches. The foregoing are only examples.

Being strict with his students and demanding intense and imaginative work, Lebedev paid no attention at all to the formal aspect of the matter. Typical in this respect is the case of P. P. Lazarev's master's examination.

The examination was given by A. P. Sokolov (theoretical physics) and P. N. Lebedev (experimental physics). The first to ask the question was Lebedev: "Do you, Petr Petrovich, know anything about hydraulic presses?" Astonished by the question Lazarev answered briefly and in most general outline. Sokolov protested: "Shouldn't you ask something more modern?" "I am finished with experimental physics; please ask the theoretical questions."

After his work on light pressure, Lebedev engaged in the question of terrestrial magnetism. He proposed that the rapid rotation of any body should lead to a certain polarization of matter and the occurrence of magnetism. The apparatus used for these experiments was typical of Lebedev. Being afraid that the tremendous speeds of rotation (up to 35 000 rpm) can disintegrate the apparatus, Lebedev cleared the room of all persons and stayed there alone. The first experiments did not yield the expected result, and Lebedev prepared to proceed to a new series of experiments of "monstrous difficulty." The work was interrupted, however, by a great political event which stirred the entire Russian progressive society.

After the revolution of 1905, the universities had considerable independence, and the greatest authority within the university was possessed by the rectorate. The political movement that began in the country in

1911 was supported by the student body. The Tsar's reactionary minister of education, Kasso, allowed the police to "rapid and decisive" measures against students' meetings. The members of the rectorate did not agree with Kasso's order and asked to be relieved of their administrative duties. But the minister went farther: He relieved the members of the rectorate not only of administrative but also of professorial duties. Then, in sign of protest against Kasso's arbitrary action, more than fifty professors and instructors left the university, among them the outstanding scientists N. A. Umov, K. A. Timiryazev, N. D. Zelinskiĭ, A. A. Éĭkhenval'd, S. A. Chaplygin, and others. For Lebedev as an experimenter, leaving the university meant not only the loss of his position, but also wrecking the laboratory he organized with so much labor. Nonetheless he felt it necessary to do his civic duty and join his colleagues.

Soon afterwards Lebedev received an invitation from the director of the Main Administration of Measures and Weights, Professor N. G. Egorov, and from the Director of the Physico-chemical Laboratory of the Nobel Institute, Svante Arrhenius, to work in their institute. Lebedev refused these offers, which would take him away from the school created by him. Then the Shanyavskiĭ Municipal University alloted means for organization of a small laboratory in two apartments located on the ground floor of the house in which Lebedev lived.* The laboratory was soon constructed and went into operation.

At the same time, using private means, the Society of Scientific Institutes started to plan a special physics institute in accordance with Lebedev's design. But he was not fated to see the end of this work. As a result of the excitement, Lebedev's health took a sharp turn for the worse, he took to his bed and passed away on March 14, 1912.

Much was written in the press on Lebedev's death. The Physical Society organized by him received a large number of letters and telegrams of condolences from Russian and foreign institutions and from many outstanding scientists.

He was buried at the Alekseevskiĭ Cemetery in Lefortovo; when this cemetery was vacated, his remains were moved to the cemetery of the Novodevichiĭ monastery.

In the Thirties, his sister, A. N. Lebedeva, in charge of the library of the Physics and Biophysics Institute, whose director was Lebedev's student P. P. Lazarev, seeing the vigorous development of physics, quantum theory of light and matter, once asked me worriedly: "Tell me, is any of his work pertinent now?" I answered that Lebedev's work has become part of science's heritage, and his name is recorded forever in this history of physics.

Further development of Lebedev's ideas can be found also in the theory of stars, in the theory of processes occurring in large-power electromagnetic currents, and in the study of molecular interactions. But, Lebedev's name will be no less valued, and perhaps even more, as that of the creator of the first Russian school of physicists. Importance is attached not only to the work and accomplishments of this outstanding school, which has enriched the world's science, but its very creation, which served as an example for the organization of similar scientific staffs.

Lebedev was in our country the initiator of the collective method of physical research, which is universally employed at the present time and which yields remarkable results. In this sense we all are his students and his successors.*

Translated by J. G. Adashko

*Building No. 20 of Mertvyĭ Pereulok (now Ostrovskii Pereulok), off Kropotkin Street.

*Lebedev's students published a number of sketches dealing with his life and work: 1) P. P. Lazarev, Journal of Russ. Physico-chemical Soc. v. 45, Physics Section, No. 3, 125 (1913); 2) A. K. Timiryazev, Outlines of History of Physics in Russia, 145, Uchpedgiz; 3) T. P. Kravets, Collected Works of P. N. Lebedev, p. 39, AN SSSR, 1963; 4) N. A. Kaptsov, ibid. p. 406; 5) S. I. Vavilov, Lyudi russkoi naukĭ (Russian Men of Science), Fizmatgiz, 1961. Besides published material, the author of this sketch used numerous verbal recollections of Lebedev by his students and persons who know him well.