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150th ANNIVERSARY OF THE BIRTH OF P N LEBEDEV

"As I deeply understand the importance and greatly admire the poetry of experiment..."* (on the eve of P N Lebedev's anniversary)

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Contents

Abstract. **Whatever we think of the eminent Russian physicist P N Lebedev, whatever our understanding of how his work was affected by circumstances in and outside of Russia, whatever value is placed on the basic elements of his twenty-year career and personal life and of his great successes and, happily, not so great failures, and whatever the stories of his happy times and his countless misfortunes, one thing remains clear — P N Lebedev's skill and talent served well to foster the development of global science and to improve the reputation of Russia as a scientific nation.**

Keywords: P N Lebedev, scientific school by P N Lebedev, history of physics in Russia

1. Introduction

If at some point in time we conceive a wish to feel pride in Russian physical science and we recall the and succession of classical figures, beginning with Lomonosov, Lents, and other celebrated physicists and ending with Nobel laureates, on the conventional curve of their scientific achievements our eye is caught by one of those unique peaks of accomplishments due to Petr Nikolaevich Lebedev.

An outstanding experimenter, P N Lebedev went down in the history of Russian and world physical science primarily due to his investigations of light pressure on solids and gases (in particular, as applied to cometary tails), the production of short electromagnetic waves, magnetism, and other scientific problems, as well as the formation of the first Russian physical school, organization of the physical community, and plans to set up a physics institute (completed only after his death).

His short active life was initially filled with overcoming external circumstances and the realization of his own imperfection, later with vigorous acquisition of the knowledge and skills that let him form a daringly complex scientific program and masterly implement it and, finally, arrive at outstanding discoveries in physics and set up a scientific school owing to his exceptional abilities, diligence, and perseverance.

It was the confrontation of Lebedev's genius, still hidden from the foreign eye, with internal (caused by his childhood with its claims to the world) and external (with acute awareness of the drawbacks of Russian existence) forces that wakened his outstanding abilities and directed his perseverance and capacity for work, which were inherited from his father, to creative activity in the physical sciences.

In our view, Lebedev the scientist is so great that it comes as no surprise that there are many publications about his life, creative activity, and subsequent development of his discoveries, and that there are many reminiscences, scientific and popular articles, and books dedicated to him. A wealth of material about Lebedev's scientific work and scientific school have also been published by the journal *UFN* over more than 90 years [1–11].

For our part, we would like to enlarge on Lebedev's personality, on those of his natural faculties and life circumstances which favored, sometimes in conflicting interaction, the development and manifestation of his genius in the realm of science, even under unfavorable conditions for science, in which he had to live and work. His example also remains instructive to us, the 21st century spectators.

* Cited from P N Lebedev's letter to N A Umov of 3 June 1896 [12, p. 135].

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2. "Little by little... I moved from engineering to the realm of science"

P N Lebedev was born into the family of an employee of a tea-trading company in Moscow on 8 March (24 February according to the old style) 1866. Being guided by the ideas of K D Ushinskii, Lev Tolstoy and other Russian writers, his father and mother decided to give their son a rather thorough primary education under home conditions, which are favorable for good upbringing.

Later, however, there emerged a conflict between son and father, who wanted his son to follow in his father's footsteps and sent him to a commercial school (Peter–Paul Schule). But Lebedev junior had a propensity for engineering and, eventually, on gaining a good command of German (which proved useful to him in the future), he left that school to obtain his father's permission in 1883 to continue education in a nonclassical secondary school. Therefore, Lebedev took his first step from the creature comforts of a businessman towards his dream — a life devoted to engineering (and later to science).

Lebedev's friendship with A A Eihenvald was an encouragement for his intentions and played an important role in his main vocation. Both dreamed of the triumph of thought rather than of day-to-day needs. At the age of 16, Lebedev had the good fortune of getting acquainted with a friend of his family's, A N Beknev, a military engineer, who amazed him by experiments performed with a homemade electrophoretic machine.

At a later time, Lebedev wrote to him with gratitude: "I continue to keep alive in my memory the amazing revolution in my world outlook, which you made with your electric machine... my life made a turn to a new path, for self-designing, the realization of my ideals... I easily overstepped the stage of repeating somebody else's experiments and set to independent work" [12, p. 142].

After a year of learning in a nonclassical secondary school, Lebedev entered and studied (1884–1887) at the Imperial Moscow Technical School (presently the N E Bauman Moscow State Technical University). There, he became familiar with scientific and technical problems, especially from N E Zhukovskii's lectures, and acquired the skills for processing different materials and the knowledge about elements of a scientific investigation in the physics laboratory of the school.

Lebedev invented a feedback controller for an electric railroad. Taking a great interest in electrical engineering, while still at the school he tried to make a carbon cell and a unipolar machine, but failed. Quite soon, attempts to understand the cause of failures led him to physics: "bit by bit I moved from technical applications to the phenomena themselves... moved from engineering to the realm of science" [12, p. 142].

3. Strasbourg saga in P N Lebedev's life

After his father's death, Lebedev, on settling his affairs, set off to Strasbourg in 1887. Starting then he was a university student at one of largest European scientific centers. Director of the Physical Institute, professor A Kundt, was a famous scientist and the founder of a vast physical school. Russian scientists (B B Golitsyn, V S Shcheglyaev, A A Eihenvald, D A Goldgammer, etc.) took study courses at the Strasbourg Physical Institute at different times.

Lebedev attended Kundt's lectures on experimental physics, sat in on the course of electricity by E Kohn, the author of one of the first courses on Maxwell's theory, and a course on electromagnetic theory of light by G Lorberg. He also attended lectures on mathematics, but he found special pleasure and benefit in his work in Kundt's laboratory. As a result, Lebedev had a thorough training in accordance with the science of the end of the 19th century.

He addressed experimental physics in an attempt to understand the cause of failure in inventive work. Furthermore — and this would play the decisive role in his future life — he was immersed in the world of experiment, masterly opened to him by Kundt with "his extraordinary talent of experimenter" [14, p. 49]. And the circumstance which facilitated mastering this world was Lebedev's technical education. By the way, his impressions of Kundt's talent and of work with him were quite strong. "With every passing day I fall in love with physics deeper and deeper. Soon, it seems to me, I will lose human appearance, I no longer understand how it is possible to exist without physics" [2, p. 406]. He also enjoyed a colloquium, which, he said, "made science familar and dear, and revealed previously unknown horizons" [14, p. 66].

When he worked with Kundt, he learned to 'think physically' and 'work physically' with the material of investigation, to imbue his mind with the spirit of the scientific method, to acquire the skills of work, overcome problems, and obtain the requisite results in the course of experiment, thereby gaining self-reliance. He would also master those features of Kundt's behavior which later proved useful to him in the formation of his own scientific school.

Lebedev spent the 1889–1890 winter semester at Berlin University, where Kundt moved for work. There, he attended H Helmholtz's lectures and reports. In letters to his mother, Lebedev noted with admiration: while "Kundt is an artist and a poet, passionate and responsive — he invokes and maintains an agitated state of spirit...", Helmholtz, for his part, "speaks lucidly and simply about eternal truths, about infinite beauty" [13, p. 11].

Helmholtz reasoned that the entire diversity of oscillations is "controlled by one common law of harmonic motion," and he himself "saw simplicity and regularity where we saw irregularity." Precisely these guesses by the German scientist would later take shape in the general-oscillatory approach to the investigation of wave phenomena in Lebedev's mind, which he embodied in his experimental activity and in the Moscow scientific school he set up [13, p. 11].

However, despite a firework of ideas and enthusiasm, which was welcomed by Kundt, and the aspiration to perform fundamental scientific work straight away and thereby prove his competence, Lebedev had to be educated in the school of failures, both in Strasbourg and Berlin, which was a blow to his self-respect. He felt the failures keenly, and they nearly broke his faith in himself. It was only due to his wise teacher Kundt that he found a way out for himself.

The way out was, Lebedev admitted, that he would no longer pursue "all-embracing, comprehensive goals..." [13, p. 12] and got down to writing (again in Strasbourg) his doctoral thesis, agreed with Kohlrausch, entitled "On the measurement of dielectric constants of vapors and Clausius–Mossotti theory of dielectrics" But, his most important acquisition, he said, was that "he felt... the art of scientific investigation was inculcated in me unwittingly and painlessly..." [12, p. 110].

Fortunately, Lebedev regarded his work on the thesis as advantageous to him: familiarizing himself with spectroscopy is beneficial and there is a chance "to do something interesting and useful"; work on the thesis requires knowledge from other areas of physics, and permits mastering the skills of blowing, alloy preparation, obtaining chemically pure gases, etc., "so that when I complete the experimental part I will be able to manage all instruments smartly" [13, p. 11]. And so it would be, indeed.

On engaging in experiment, Lebedev wrote in his letter: "My work is advancing quite successfully.... Now I am perfectly contented with everything and don't worry... about my future research activity, for I feel that I am holding a real bird in the hand, which is better than two in the bush". A few days later he remarked with great satisfaction: "...I could say that my work is the most elegant and nontrivial of all now performed at the institute — it's something at least" [13, p. 13].

He performed the requisite experiments skillfully, and in doing so proposed a new method for the vapors of high-boiling substances and tested it in the determination of their dielectric constants, passed the required examinations, and obtained the degree of Doctor of Natural Philosophy in 1891. On Kohlrausch's advice, Lebedev's paper was published in the leading scientific journal *Annalen der Physik*. This work was met with approval. After defending the thesis, Lebedev continued to work in the laboratory for some time.

Somewhat earlier, however, Lebedev applied Maxwell's conclusion about light pressure to the deviation of cometary tails by the Sun and proved that light-induced repulsion should exceed Newtonian attraction for small particles, and in this case the tail deviations were attributable to the light pressure. He reported this theoretical work at Kohlrausch's seminar and published it in Russia in 1891 and in Germany in *Annalen der Physik* in 1892 in German (the paper was also reprinted by the journal *Philosophical Magazine* in English). This paper made Lebedev known.

So, the example of Kundt's concentration on separate scientific problems and the experience of work on the thesis had a 'sobering' effect on Lebedev and convinced him to take up a minimal number of problems significant from the standpoint of electromagnetism and substance structure. Reconsideration of his own potentiality led him to that spiritual 'maturity' which would underlie the success of his activity for many years to come.

Lebedev's activity was also favored by the knowledge of discoveries owing to H A Lorentz (Lebedev would discuss with him the repetition of Rowland–Hilbert experiment by Lorentz in 1903) and to Max Planck. Lebedev was friends with Planck, whom he initially believed to be an ordinary physicist. However, on learning of his merits in predicting energy quanta, Lebedev would playfully say that he refused to regard Planck as a living legend: "After all, we danced quadrille!"

Lebedev positively appreciated also the theory of relativity. This is attested by two facts. In 1911 he emphasized that the hypothesis about the existence of ether "was superfluous and no longer necessary" due to the relativity principle [14, p. 366] and suggested that his pupil P S Epstein[1] should engage in relativism. For Lebedev himself, it was experiment and not theory that would become the principal element of his scientific creative activity.

Eventually, Lebedev outlined a consistent program for investigating different kinds of oscillations, which comprised the necessary theoretical considerations, their corresponding experimental investigations, possible consequences, and explanations of several effects. He successfully reported this program in his last address to Kohlrausch's colloquium and got down to its implementation in Russia later.

However, its realization would not proceed precisely the way he would have wanted. One hindrance lay with Lebedev's natural desire to comprehend the fundamental secrets of Nature and finally apprehend all, which he suppressed but which manifested itself from time to time. Another reason lay with a variety of circumstances encountered in life, which he could not pass by due to his human decency and fairness.

His short wavelength research and work on stellar motion, design of instruments, participation in a conference of scientists and physicians; A Kundt's and later A G Stoletov's deaths; the discovery of X-rays by K Roentgen; and concerns for his scientific school — these humanly explainable breaks in his work on the program were painfully endured by Lebedev, about which he repeatedly wrote to Kohlrausch.

4. Hearth and home and international recognition of the Russian scientist

So, on returning home in 1892, Lebedev ran into several difficulties and encountered contradictions both in life and in science. Nevertheless, he who had enjoyed scientific work abroad intended — together with B B Golitsyn — to transfer to Russia the traditions of his valued Strasbourg school (with its laboratories, colloquium, and the prospect of publishing in the future the work of his pupils in the leading European scientific journals).

On returning to Moscow, Lebedev worked at Moscow University, where A G Stoletov offered him the position of assistant at his laboratory. It was not long before Lebedev equipped his own laboratory, joined the work of Moscow societies, and organized, together with Golitsyn, a series of reports and reviews on the latest achievements in physics, which were held at the Society of Devotees of Natural Science, Anthropology, and Ethnography. Thus began his activity.

At the 9th Meeting of Scientists and Physicians, Lebedev demonstrated H Hertz's experiments with retention of their initial form. For the participants in the meeting, his magnificent demonstrations became an obvious substantiation of Maxwell's theory and brought our hero recognition from physicists and teachers. Thanks to Lebedev, Maxwell's ideas obtained a permanent place in the minds of his compatriots.

Being engaged in teaching and instrument making, Lebedev did not abandon his program. His work on comets impelled him to turn to astrophysics and later to the very problem of electromagnetic wave interaction with the molecules of substances. For his doctoral thesis in Russian conditions, Lebedev carefully prepared an experimental investigation of the mechanical action of waves on molecules as assumed resonators.

In the Introduction to the thesis, Lebedev substantiated the topicality of the investigation: "the problem of radiation sources, about the processes occurring in a molecular vibrator

[1] Theoretical physicist P S Epstein (1883–1966), a private lecturer at Moscow University, embarked on the path of science in 1904–1910 with P N Lebedev, then left for Germany to work with A Sommerfeld on Lebedev's advice, subsequently worked in Switzerland, and settled down in the USA. He published papers on the theory of diffraction, quantum theory, and the problems of quantum mechanics. A member of the National Academy of Sciences of the USA, two of his papers were published in the journal *Uspekhi Fizicheskikh Nauk* [15, 16].

while it donates light energy to the ambient; this problem leads us, on the one hand, to the area of spectral analysis and, on the other, as if quite unexpectedly leads to one of the most intricate problems of modern physics — to the theory of molecular forces" [14, p. 68].

In doing this, Lebedev pointed to the case "when many molecules act on each other simultaneously, their vibrations not being mutually independent owing to their close proximity. If it becomes possible to solve this problem some day, by using the data of spectral analysis we will be able to predict the magnitudes of intermolecular forces... specify their temperature dependences", and eventually find out whether molecular forces belong to electromagnetic ones [14, p. 69].

With time, it became evident that this problem could not be solved by Lebedev, for quantum mechanics had not yet made its appearance and the structure of molecules had not yet been studied. The solution was obtained in the middle of the 20th century first by H Casimir jointly with D Polder, and later in the work by B V Deryagin (Derjaguin), I I Abrikosova, and E M Lifshits [9]. The theory of attractive forces between condensed bodies was developed by E M Lifshits. Lebedev's prediction came true.

His investigation itself lasted from 1894 to 1897 and was drawn up in the form of a thesis in 1899, which he defended in 1900. At the beginning, he made a remark: "There is no way to experimentally investigate in a simple form the action of light on individual molecules of some body. And so I turned to experiments with long Hertz waves to make them act on a conventional 'molecule', which possesses the properties of interest" [14, p. 70], i.e., on a resonator with a torsion thread.

In conclusion, Lebedev noted: "... the complete identity in the action of ponderomotive forces, which was observed for quite different oscillatory motions — electromagnetic, hydrodynamic and acoustic oscillations — suggests that those elementary laws which describe the observed phenomena should be independent of the physical nature of these oscillations and their receiving resonators" [14, p. 121]. A year after the presentation of the thesis he became a professor at Moscow University.

At that time, Lebedev made a device for generating and receiving millimeter electromagnetic waves with a wavelength of 6 mm and observed their reflection, birefringence, interference, etc. Via his work, as we see, the scientist consistently and irrepressibly approaches his most important investigation — the experimental measurement of light pressure, the scientific achievement which the well-known scientists O Frenkel, W Crookes, A Righi, A Bartoli, etc. had tried to accomplish in practice.

By the time the addressed his main concern in science, Lebedev had learned the foundations of theoretical and experimental physics, as well as Kundt's and Kohlrausch's lessons for conducting experiments, had learned the essence of the experimental method in practice, and apprehended the special thinking and practical intuition of the experimenter, had comprehended the central statements of the Maxwell theory and, furthermore, had mastered the innovation skills under the laboratory conditions of his time, and so was fully prepared in mind and body for executing these experiments.

Prior to this, Lebedev had repeatedly mentally carried out his experiment to measure the pressure of light on bodies. As E Mach noted at that time, "we experiment mentally at lower expenses. And so it comes as no surprise that a mental experiment precedes the physical one and prepares it" [17, p. 195]. But, as would be expected, the reality of Lebedev's experiment itself would repeatedly introduce corrections to his mental models and generate doubts of various kinds in his mind.

Over theses years, Lebedev got accustomed to his main scientific problem and its subtleties. Finally, based on Maxwell's well-known conclusion that "there exists in a beam a pressure which is exerted in the direction of travel (i.e., perpendicular to the wave front — *R Shch*) and is of a magnitude numerically equal to the energy per unit volume of the beam" [18, p. 341], and relying on his own theoretical considerations and conclusions, on an analysis of his predecessors' attempts, and on the mental planning of the conditions required for his experiments, in 1899 Lebedev made a facility which met his prescribed parameters.

In his facility the light emitted by a voltaic arc was incident on a small light wing suspended on a thin thread in a glass vessel. The air was evacuated from the vessel, and the light pressure could be judged by the thread torsion. To eliminate gas convection, the light was directed alternately on either side of the wing. Radiometric forces were weakened by increasing the vessel volume and lowering the pressure. As a result, the radiometric forces and convection streams were substantially lowered, which permitted measuring the light pressure.

As emphasized by Lebedev, according to his measurements, "a light beam incident on reflective or absorptive flat surfaces exerts pressure on them, which is equal, to within the experimental error, to the light pressure according to Maxwell–Bartoli" [14, pp. 181–182]. He reported the technique of his measurements to the Inaugural International Congress of Physics in August 1900 and published it in the *Journal of the Russian Physicochemical Society*. In Russia, in 1904, Lebedev was awarded the prize of the Imperial Saint Petersburg Academy of Sciences.

K A Timiryazev, a physiologist and historian of science and a member of the Moscow Physical Society and the Russian Physicochemical Society, attended the congress. On meeting with W Thomson, Lord Kelvin, who had immense prestige with the scientific world at that time, Timiryazev heard from him the following estimate of the significance of the proof of light pressure: "Perhaps you know that I have always disagreed with Maxwell and did not accept his light pressure, but your Lebedev made me surrender with his experiments" [19, p. 62].

Even in late 1900, F Paschen, in a letter to Lebedev, praised his work: "I regard your result as one of the most important achievements in physics made in recent years and do not know which to admire more: your art of experimenting or the conclusions of Maxwell and Bartoli. I am aware of the difficulties of your experiments and appreciate them, the more so as some time ago I was doing similar experiments... however, they did not yield positive results..." [12, p. 171].

However, congratulations on the occasion of the experiments already made by Lebedev did not go to his head. He had formed a habit of carrying out any investigation to its logical end, and, knowing some of its small defects, he intended to bring to perfection the work which had already brought him world recognition. At the end of June 1901, he frankly wrote in a letter to N P Kasterin: "Now I am 'putting the finishing touches' on the light pressure work. I feel better now and will readily work in the lab throughout the summer..." [20, p. 572].

In 1901, Lebedev was also congratulated by W Crookes, who discovered radiometric forces (Crookes radiometer):

"Dear Mr. Lebedev... You have undoubtedly reached great success by discovering and measuring an extremely weak force caused by the direct action of light, because it is masked and complicated by a substantially stronger radiometric action" [12, p. 198]. According to Lebedev's words dated 1902, congratulations from the world's leading physicists "show that the work proved successful" [12, p. 201].

On completion of the experiments on light pressure on solids, Lebedev decided to establish a colloquium at the laboratory, during which he delivered a course on physics news and simultaneously published several papers and popular articles. One of them was entitled "The scale of electromagnetic waves in ether" [14]. It did not merely summarize the effects of the electromagnetic radiation theory and outline the future extension of this theory; with time, the scale itself would acquire the status of one of the most commonly used teaching aids, whose appearance became quite typical for physics laboratories both in schools and at institutes of higher education.

However, Lebedev inherited from his father not only persistence in reaching the objectives set before him, but also heart disease — "a continuous unbearable dying" in his words [20, p. 598]. He had to interrupt his research for months, suspend lecturing, and go abroad for medical treatment. It was also so after the measurements of light pressure. And it was not until the scientist somewhat improved his health that he set himself the task of measuring the pressure of light on gases.

The majority of scientists believed this task to be unsolvable, because the light pressure on a diatomic molecule was extremely low in magnitude. And so Lebedev decided to measure the total pressure experienced by many gas molecules rather than by one. To this end, he made around two groups of ten highly sensitive instruments and used a mixture of the most suitable gases to solve this daring experimental task in early 1909.

At precisely this moment in his life, the 43-year old Lebedev experienced an extraordinary burst of energy and rational and emotional self-confidence as a researcher: "I am really in love with my science again, in love like a boy, just like before: I am carried away, work throughout the day as if I was never ill — once again I am the same as before: I feel psychologically strong and fresh, I play with difficulties, I feel that I am Cyrano de Bergerac in physics..." [20, p. 602]. This state conduced to the success of the work.

Lebedev assumed that "when a beam of white light passes through a gas layer possessing selective absorption, the light rays should make the whole mass of the gas move in the direction of light propagation by exerting pressure on individual molecules." Using acetylene and carbon dioxide with the addition of hydrogen, he made the necessary measurements to arrive at the conclusion that "the existence of light pressure on gases has been experimentally determined" and that "this pressure, in magnitude, is directly proportional to the energy of the light beam and the gas absorption coefficient" [14, pp. 301, 321].

Lebedev reported the next verification of the Maxwell theory to the Mendeleev Congress and the Congress of Natural Scientists in 1907 and 1909, and published the work itself in 1910 in Russian (*Journal of the Russian Physicochemical Society*), German (*Annalen der Physik*), and English (*Astrophysical Journal*). At that time, Lebedev became the first Russian physicist elected an honorary member of the Royal Institution of Great Britain. He expressed his thanks for the election and receipt of the corresponding diploma via G Young, secretary of the institution.

To summarize Lebedev's scientific activity in the area of physics, we are reminded, first, of the continuation of his experimental research by a series of scientists from several countries, beginning with J Poynting and ending with the experiments of A Compton and O Stern, already from a quantum standpoint, and, second, that the motives of his scientific preferences served as helpful material for preparing his pupils for fruitful scientific activity.

A quarter of a century after Lebedev's decease, a pupil of his pupil S I Vavilov wrote that the work of an outstanding Russian scientist on light pressure "is not a separate episode but an experimental junction of paramount importance, which determined the development of the theory of relativity, the theory of quanta, and modern astrophysics," while "the example of Lebedev's laboratory itself with its numerous pupils and staff members served as a basis for setting up several physical research institutes in our country" [21, pp. 166, 167].

Lebedev's experiments on light pressure were appreciated by leading scientists. In 1905, Lebedev became a nominee for a Nobel Prize. O D Khvol'son (the author of the famous "Course of Physics") nominated him as well as the English chemist and physicist J Dewar without any substantiation of his proposal. Argumentatively substantiated was the nomination sent to Stockholm in 1912 by the German physicist W Wien, a 1911 Nobel Laureate, who nominated Lebedev together with Albert Einstein and Hendrik Lorentz.

In his message, Wien emphasized that "Lebedev demonstrated how it is possible to obviate the interfering effect of extraneous forces and make quantitative measurements of light pressure" [22, p. 68]. No nominations were made by Russian scientists. Wien's nomination did not manage to work: on 14 March Lebedev passed away. Lebedev's nomination actually ushered in a series of unaccomplished, for a variety of reasons, Nobel Laureates from Russia [23].

Lebedev's international prestige increased already after his experiments on light pressure on solids. In 1902, it was proposed that he express his vision of possible nominees for a Nobel Prize in physics, to which he replied: "I express my gratitude to the Committee for the honor... I will not fail to use this proposal" [12, p. 223]. However, for reasons still unknown, the scientist never fulfilled his promise.

Lebedev was simultaneously concerned with the nature of terrestrial magnetism, whose study was pioneered by W Gilbert. Lebedev staged experiments to discover the magnetic fields of rotating bodies of 'huge mass', which succeeded only with 'negligible ones'. In his first and last report, he noted that the hypothesis of the formation of such fields does not stand up to "direct experimental verification" [14, p. 334]. Although Lebedev continued these experiments, they were not fated to be completed.

So, being convinced that "nature is an indivisible harmonic unity" and trying to find this unity in practice, Lebedev initially associated it with Newtonian mechanics. As he mastered Maxwell's theory, he assumed the unity to be in "the electromagnetic faith", which permitted explaining the nature of molecular forces, and finally in wave motion, "whereby the pressure on obstacles and resonators comes out in a natural way" [12, pp. 76, 120, 206].

The emotionality and the youthful aspiration to understand the entire world of physics, which were inherent in Lebedev's personality, affected the realization of the research

program, which had its inception under the beneficial circumstances of Strasbourg. Perhaps, this was 'promoted' by the difficulties in understanding the successive stage of the experimental task and the desire to make a contribution to extra-program areas of physics.

This is usually work of nonfundamental scientific significance or applied work related to teaching tasks. The scientist also took up the problems of acoustics and ultraacoustics. Lebedev's extra-program work permitted him to perfect his experimental skill, develop his intuition, and thus revert to the central cause of his life with renewed strength.

5. P N Lebedev's ideology in the life of his scientific school

In expounding his views on the role and significance of experiments in the progress of science in the early 20th century and supporting Lebedev's similar viewpoint, S I Vavilov wrote: "In the stormy ocean of theories and 'viewpoints', facts are immobile and firm, as before, and an experimental physicist can calmly look from his stronghold on the raging waves and prudently select the necessary guides" [1, p. 192].

To imagine Lebedev the experimenter, who adopted his teacher's methods, we turn to the reminiscences of Lebedev himself: "Kundt is an experimental physicist who does not try to guess and explain nature but, by taking advantage of his exceptional talent, makes it speak and answer a series of questions systematically posed to it" [14, p. 58].

With his experimenter's skill, Kundt was amazing through the simplicity and elegance of his methods, the ability to overcome difficulties, and his inherent resourcefulness, diligence, and persistence: "much of his seemingly simple work concealed a lot of labor" [14, p. 59]. In fact, the same qualities were inherent in Lebedev. Remembering Kundt, we also imagine Lebedev himself.

Thanks to Kundt, Lebedev became a self-reliant researcher with an original style. While he adopted much from Kundt, Kundt also admired Lebedev and would hold him up as an example to his other pupils. Learning from Kundt and accumulating knowledge brought him to the level of important physical problems and extended the scale of his work. Lebedev's scientific program, which was aimed at the pressure of light and waves in general, led him to a broad range of experimental physical problems related to the essence of wave processes and the interaction of waves and radiation with matter [24].

In his letter to N A Umov, Lebedev wrote: "I deeply understand the importance and greatly admire the poetry of experiment...," and therefore "...delivering lectures in the area in which I will work from now on and probably till the end of my life — this lecturing will open up new horizons to me and make me consider many things, which will impel me to creatively work to elucidate the problem itself..." [12, p. 135].

In a letter to Golitsyn, Lebedev emphasized the complexity of the cognition of nature: "...a human being constructs theories, intends to improve and simplify nature — but when a theory is brought together with experiment, it falls and is thrown overboard. In his blindness, the human gives way to despair, for nature is reluctant to follow his 'simple' laws, but he forgets that he is analyzing a single isolated fact without relation to all the rest..." [12, p. 76].

Following the traditions of Kundt's school, Lebedev avoided detailed theoretical calculations and confined himself to elementary mathematics. Characteristic for him were the principles of reasonable logic, simplicity, and continuity of experiment formulation determined by the reasonable rightness of investigation stages on the way to the formulated goal and, lastly, resuming in the form of a paper of minimal size.

As noted by T P Kravets, Lebedev's brevity in outlining his conclusions was reflective of the economy of his thought and action. "One should not deceive oneself about the small volume of his works: sometimes, one line in his work corresponds to many days of labor and reflection. Everything written by him marks a certain step in the progress of his thought, and therefore he wrote relatively little..." [25, p. 283].

It should also be remembered that the equipment in Russian laboratories was quite poor at that time. L A Artsimovich came to see their poor setups and wrote: "Under these conditions, one of the main guarantees of success was the handicraft skill of a scientist and his mastering of all kinds of technical skills... He would make the most critical components of every new experimental facility with his own hand and assemble it from beginning to end in his laboratory" [26, p. 145].

Both his disposition to labor and his physical strength, training, which were acquired in youth when going in for rowing and mountaineering, and stamina accumulated in scientific activity turned out to be appropriate, i.e., he had precisely those reserves that should be inherent in an experimenter and which perhaps held in check, at least partly, the manifestation of his heart disease.

Lebedev adopted the traditions of the school of Kundt and Kohlrausch and saw the purport of his homeland activity both in the development of science and in teaching the experimental method, especially when young people manifested an aptitude for physics research, the yearning to master the requisite skills, and efficiency in solving experimental problems.

According to his observations, in preparing young scientists, "until now, they have had to merely prepare a summary of their work, while I insist that experiments referred to in the work be demonstrated by all means — the difficulty and laboriousness lie in the fact that researchers use homemade instruments...." Concerning this request of his, Lebedev noted with satisfaction: "What makes me glad is that my idea of a demonstration has found acceptance, at last..." [13, p. 17].

His scientific style showed up in advice to young scientists: "do strive for an exterior beauty of the instruments... no research proceeds without a hitch, one should always be prepared for that and take it easy... start writing your paper right now... so that it is convincing to an outsider... retaining all that is necessary and omitting everything unnecessary... only by concentrating all your thoughts on the work will you be able to achieve the maximum of what is within your power" [20, pp. 578–579].

In the course of his activity, Lebedev set up a physical school with its own scientific program and a seminar, which grew to about thirty participants by the end of his life. P P Lazarev, N N Andreev, V K Arkad'ev, A S Predvoditelev, N A Kaptsov, A R Kolli, T P Kravets, V D Zernov, A B Mlodzeevskii, V I Romanov, K P Yakovlev, and others considered themselves his pupils. Lebedev's school carried out work on wave pressure, to which Lebedev devoted his life.

In this case, Lebedev said that he "had impelled and would impel people to devote their time and labor to the solution of scientific problems only in the case of innate talent, the talent to understand, feel, and guess the harmo-

nious relations in the eternal laws of nature — the talent which opens before a scientist the boundless field of diverse and highly fascinating research activity" [1, p. 345].

He was convinced that the education of a pupil is also determined by the talent of the teacher himself. And the greater the talent, "the broader the prospects he opens for the pupil, the more exact and deep is his vision; the pupil gets accustomed to this vision and day after day receives evidence that it is correct, and the pupil comes to unwittingly consider this vision as his 'own'" [20, pp. 565–566]. This is quite a lot to begin with.

According to Lebedev, an important indication of the fruitfulness of his scientific school was the development in his pupils of the aspiration to learn how conduct such research which could be published in European journals, thereby fostering a rise in the level of physical research in Russia. His efforts were not in vain: this is convincingly attested to by the progress in Russian physical science in the first half of the 20th century.

To summarize the features inherent in the personality of P N Lebedev as a scientist, he should be characterized as an experimental physicist and a representative of A Kundt's school, who won world recognition and was oriented toward the world community; he was the founder of Russia's first school of physicists and a seminar leader, who was indifferent to public and enlightening activities [24].

6. P N Lebedev's close and distant surroundings

It is worth recalling a trivial truth: the activity of a scientist without the exchange of ideas and hypotheses with colleagues, without their opinions and assessments, discussions, and debate is usually inefficient and sometimes loses all its attractiveness in the scientist's own opinion. Lebedev's circle of communication included European and Russian scientists. This is attested to by Lebedev's memoirs and correspondence [12, 13, 19].

We mention his colleagues and friends who were close to him as regards scientific and everyday (worldly) interests: among the domestic ones were Eihenval'd (magnetic fields of displacement current and moving electrified bodies), Golitsyn (radiation temperature and seismology [27]), and partly Stoletov (electromagnetism and the external photoeffect [28]), and among the foreign ones were Kundt, Helmholtz, and Kohlrausch, who are known to us by the Strasbourg saga of our hero.

The youth friendship between Lebedev and Eihenval'd also continued at a later time. Both were enthusiastically engaged in experimental physics; Eihenval'd, with his theoretical thinking and whose work was highly appreciated by Lebedev, was a participant in his colloquium. When Lebedev established the Physical Society, Eihenval'd became a member and its president. In 1920, he left Russia forever. He deceased in Milan in 1944.

Lebedev became good friends with Golitsyn in Strasbourg and noted that Golitsyn "was engaged in physics with love but without enthusiasm...." Lebedev kept his letters as "the richest in content" [13, p. 9, 12]. They discussed important problems of science and scientific life. Tension in their relationship arose after the events around Golitsyn's thesis. Golitsyn passed away 4 years after Lebedev's death.

Lebedev owed Kundt the learning of experiment as well as the apprehension of its philosophy and poetry: "I never expected that a man could so wonderfully 'enchant' me as my patron does, not even with words but with his genius: I cannot name this direct effect otherwise.... I am afraid I will start knitting him a Christmas stocking" [13, p. 9].

An important role in Lebedev's selection of the central scientific idea for the remaining years of his scientific activity was played by Helmholtz [13]: his lectures and reports, and primarily his conviction that "individual processes in nature may be reduced to common rules and may be derived again from the latter" [29, p. 180]. This idea of unity underlay Lebedev's research.

The formation of Lebedev's skill for precision measurements and of his taste for them was fostered by Kohlrausch. Their correspondence contains discussions of Lebedev's work and their publications talk about his successes and failures, his illness and its treatment, fatigue, and sometimes the loss of interest in research in Russia [12, p. 175]. Kohlrausch's sympathy with his pupil and his support were vitally important for Lebedev.

In 1894, Kundt and Helmholtz passed away. Kohlrausch died in 1910. Fortunately, Lebedev's connections with S Arrhenius, G Wiedemann, O Wiener, H A Lorentz, F Paschen, H Rubens, and others continued. On Lebedev's return to Russia, his meetings and correspondence with them were supplemented with contact with A G Stoletov, N A Umov, O D Khvol'son, I I Borgman, P S Ehrenfest, N N Shiller, and others.

During these years, Lebedev greatly needed their support, and especially Stoletov's support. Stoletov immediately recognized Lebedev's skill as an experimenter and did a lot for him. However, Stoletov (and not he alone) treated disapprovingly, and sometimes even sarcastically, the problem Lebedev was engaged in: "Why have you disappeared? Is it that you have been shattered by influenza or light pressure?" [12, p. 129].

At the same time, Lebedev's advice fostered the scientific life of Moscow and other scientific centers scattered over Russia. He supported and encouraged the research of other scientists, should they apply to him for help, and also arranged the professional life of his pupils in their new positions. It should also be remembered that Lebedev maintained a vast correspondence with Russian colleagues and devotees of physics.

In fact, Lebedev performed his research in close contact with European and Russian scientists. His indomitable advancement to world-class discoveries leaned upon their work, was fed by them, was compared with them in disputes, and fostered on aspiration to reach the objective, leaving behind itself ideas and discoveries, hypotheses and insights, which were beneficial to generations of scientists.

However, Lebedev's creative activity was adversely affected by social effects like debates at the university concerning conferring a doctoral degree upon him, the difficulties in equipping his laboratory and, towards the end of his life, the events of 1911 — an emotional experience which was detrimental to him and his cause. Nevertheless he remained an outstanding creative personality.

7. P N Lebedev's school on the verge of possible failure

In 1911, in protest at the reactionary actions of Minister of Education L Kasso, Lebedev left the university, along with many lecturers. As a result, Lebedev lost everything: "Historians, lawyers, and even physicians — they can leave

Photograph. Petr Nikolaevich Lebedev Gold Medal.

straight away. But I have a laboratory and, most important, over 20 pupils, who will all follow me. To interrupt their work is easy, but to find a place of work for them is difficult...'' [13, p. 23].

In the same year he wrote: ''If Russian society... realizes its moral responsibility to humanity to place science in conditions in which it can exist and advance, if it wishes to protect it from unexpected shocks in the future, society can do this by setting up laboratories concerned with scientific investigations...'' [14, pp. 339–340].

During the hard times for his work, Lebedev began to doubt his future work in Russia: ''For the first time I realized clearly: if I sill have the strength to work as a scientist, I will have to find a place of refuge in Europe'' [2, p. 378]. The more so as invitations came from both Russian and European science institutions, including S Arrhenius from Stockholm, who promised to provide Lebedev the necessary conditions.

Despite these invitations, Lebedev nevertheless remained in his fatherland. This was aided by the private funds of a Moscow society, which recognized Lebedev's significance for Russian science. These funds eventually enabled him to set up a new laboratory at A L Shanyavskii Moscow City People's University. Private benefactors collected the funds for building a new special Physical Institute for Lebedev [30].

But it was too late. On 14 March 1912 P N Lebedev passed away. His closest friend, K A Timiryazev, wrote in his obituary: ''I have never met a man in whom a brilliant and creative mind is so harmoniously combined with a remarkable endurance in labor, and the physical strength and handsomeness merge with a sparkling wit and infectious cheerful joviality'' [20, p. 75].

Eihenvald, who spoke of the proof of light pressure as ''the summit of the experimental art of contemporary physics'' [20, p. 77], was upset about the death of his friend and relative: his sister — V A Eihenvald (later Deryagina) — had been Lebedev's wife since 1908. Initially, P N Lebedev was buried in the Alekseevskoe cemetery. After its closing, the ashes were transferred to Novodevich'e cemetery.

About 100 condolence telegrams and letters arrived from Russian and European scientists. H A Lorentz wrote the following heartfelt words: ''I regarded him as one of the first and best physicists of our time and admired how he managed to preserve — under unfavorable conditions during the last year — the Moscow school he had established and how he managed to continue the general work'' [12, p. 453].

By preserving his school, Lebedev thereby handed down a legacy of not only his scientific work but also the work of his young successors. They, like their teacher, did more than continue developing Lebedev's areas of science. Having preserved Lebedev's traditions and enriched them with their own comprehension, several of his pupils set up new scientific schools, which testified to a new stage of scientific life in the country.

The name of Petr Nikolaevich Lebedev was given to the Physical Institute of the USSR Academy of Sciences (LPI) and a gold medal (see the photograph) conferred by the Presidium of USSR AS (presently by the Presidium of the RAS) every three years (since 1969) for the best work in the area of physics. This honorable medal was awarded to A I Shal'nikov, V B Braginskii, I K Kikoin, V S Vavilov, and others. Lebedev's traditions are now being continued and developed by the staff of the P N Lebedev Physical Institute (LPI) of the Russian Academy of Sciences.

8. Summary of P N Lebedev's service to science

When summarizing Lebedev's life as a physicist, which was short from the present viewpoint, special emphasis should be laid on the instructiveness of his creative career. It embraced self-confidence and disappointments, the awareness of his own ignorance and the aspiration to get rid of it, and the pursuit of mastering the method of science for the practical implementation of his bold plans.

First, his investigations to measure light pressure were an additional substantiation of the verity of electromagnetic field theory, according to which a radiation flux possesses energy. However, his work also retains significance under the quantum approach, since the existence of light pressure permits treating light as a flux of photons possessing energy and momentum.

According to the conviction of scientists, which corresponded to the contemporary state of science and was stated by J Poynting in 1905, inherent in the light pressure is such ''smallness which eliminates its consideration in terrestrial matters'' [31, p. 102]. The pressure of a laser beam on atoms becomes strong when the radiation frequency coincides with the atomic transition frequency.

Second, by forming Russia's first scientific school and seminar, Lebedev laid the basis for educating a group of young physicists, some of whom came to be the founders of their own scientific schools (P P Lazarev, N N Andreev, V K Arkad'ev, N A Kaptsov, T P Kravets), and established the tradition of collective research work, without which it is hard to imagine modern science.

Third, Lebedev, with his commitment to the ideals of science, unique working capacity, and Nobel-level discoveries, who avoided participation in everyday events but proved to be a true citizen at the crucial moments for Russian science and education, exerted significant influence on the scientific community of his time. He was more than a scientist for society.

And, fourth, his emotionally bright and simultaneously rationally practical life path filled with a healthy spirit and a struggle with the indisposition of a purposeful man with his thoughts and acts, defeats and victories is one of the most valuable versions of a "manual of life," for a young Russian man who intends to work for his homeland, regardless of its destiny.

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