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In Memory of Leonid Isaakovich Mandel'shtam

(On the 85th anniversary of his birth and the 20th anniversary of his death)

FROM THE EDITORS

The past year has marked 85 years from the birth and 20 years from the death of the eminent Soviet physicist Academician Leonid Isaakovich Mandel'shtam. Mandel'shtam was a scientist who stood on a level with the greatest physicists of our time. He made a vast contribution to the development of optics, radiophysics, and the theory of non-linear oscillations, and founded new approaches in these fields of physics. Many leading Soviet physicists proudly call themselves his students, and continue to develop his ideas in physics.

A new generation of physicists has grown up in our time who know little of the way in which many modern approaches in physics are indebted to the ideas of Mandel'shtam. The scientific council of the P. N. Lebedev Institute of Physics of the USSR Academy of Sciences scheduled a special session on November 27, 1964 in his memory. The introductory speech by I. E. Tamm and other reports at this session cast light on some aspects of Mandel'shtam's scientific work and the development of his ideas in the studies of Soviet physicists.

The editors have deemed it worthwhile to publish the proceedings of this session.

CHARACTERISTIC FEATURES OF THE WORK OF LEONID ISAAKOVICH MANDEL'SHTAM

(Introductory speech)

I. E. TAMM

Usp. Fiz. Nauk 87, 3-7 (September, 1965)

MAY 5th of this year (1964) marks 85 years from the birth of Leonid Isaakovich Mandel'shtam, while today, November 27, is the 20th anniversary of his death.

Mandel'shtam made a permanent creative contribution to the development of physics, and greatly influenced its growth in our country.

Having an exceptional gift for teaching, he put much effort and time into teaching activity. He founded a brilliant school of Soviet physicists; among his students it suffices to mention A. A. Andronov, G. S. Landsberg, M. A. Leontovich, S. M. Rytov, and S. É. Khaĭkin. I am also proud to have been his student.

We know from the history of science that, depending on a number of contributory circumstances, some scientists acquire fame beyond their true merits. Conversely, others are underestimated by their contemporaries and successors. In spite of the fact that Mandel'shtam's name enjoys wide renown, still there is no doubt that the significance of his creative work has not been adequately recognized. One of the reasons for this was his unusual modesty and self-criticism. I shall give just one example as an illustration.

In the last years before his death, N. Bohr repeatedly emphasized in his articles and oral reports what an important role Einstein's critical attitude had played in the development of the foundations of quantum mechanics. Over many years, Einstein had periodically published articles in which he tried to refute the principles of quantum mechanics by analyzing "thought experiments" which led, in his opinion, to paradoxes. Just as regularly, N. Bohr would publish reply articles in which these paradoxes were refuted and explained away. Of course, this required very deep analysis and penetration to the essence of the phenomena, which considerably facilitated the clarification of the foundations of quantum mechanics. However, no one but his closest students knew that Mandel'shtam himself would immediately make an analysis and refutation of each successive critical article of Einstein. When we asked him to publish his ideas, he always refused on the grounds, as he said, that Einstein was such a great man that he surely knew something that he, Mandel'shtam, didn't. Several months would pass, and N. Bohr's reply article would appear. It always turned out that its arguments coincided with Mandel'shtam's ideas.

We can distinguish several fundamental lines in his very many-sided creative work: optics, radiophysics, the theory of non-linear oscillations, and in the last period of his work, quantum mechanics. I shall briefly touch upon just two of these lines.

The varied phenomena involving light scattering attracted Mandel'shtam's attention throughout his life. As early as his professorial dissertation in 1907, he discovered an error in the Planck-Rayleigh theory prevailing at that time, according to which light scattering in media can be simply due to their molecular structure. He showed both theoretically and experimentally that homogeneous media do not scatter light, and that scattering is due to inhomogeneities in the medium. Subsequent studies by M. Smoluchowski, A. Einstein, and by Mandel'shtam himself, showed that these inhomogeneities are due to statistical fluctuations in the density of the medium.

In the course of these studies, he predicted that in the scattering of light by an elastic medium, we should observe a splitting of the wavelength of the scattered light due to a peculiar Doppler effect. This is because the light is scattered by the thermal elastic waves in the medium, which move at the speed of sound. An earlier study by Brillouin had contained an indication of this phenomenon, and hence it has been termed the Brillouin-Mandel'shtam doublet. In particular, he calculated the relation of the frequency shift of the light to the scattering angle, and in the middle twenties he and G. S. Landsberg set up experiments to detect this effect. During these studies, the two scientists made a remarkable discovery, that of combination scattering of light (Raman scattering). The latter produces a much greater frequency shift in the scattered light than the Doppler effect does. It is due to addition of the frequency of variation of the refractive index of the medium arising from its elastic thermal vibrations to the light frequency. In quantum language, this means that, when scattered, a photon can either absorb or emit a phonon, i.e., a quantum corresponding to the elastic waves in the medium.

Combination scattering has a very wide field of applications, but unfortunately, the Nobel prize for the discovery of this phenomenon was awarded to the Indian physicist Raman, instead of L. I. Mandel'shtam and G. S. Landsberg. They discovered this phenomenon late in 1927. However, they retested it repeatedly, attained a high accuracy of measurement, and published their first report only in the spring of 1928, when they could provide in the report an exact theory of the new phenomenon confirmed by measurements. However, by this time Raman had published several very short communications containing qualitative indications of an analogous phenomenon that he had discovered in liquids (L. I. and G. S. had experimented on crystals), and moreover, with an incorrect interpretation.

We note that the Brillouin-Mandel'shtam doublet, the search for which led to the described discovery, was also observed experimentally. There was no optical apparatus good enough then at Moscow University, where Mandel'shtam was working at that time, and he suggested to Professor D. S. Rozhdestvenskiĭ in Leningrad, who had such apparatus at his disposal, to make the appropriate measurements. Rozhdestvenskiĭ assigned them to his student E. F. Gross, who set up the experiment and was the first to observe the sought line splitting in the scattered light. I. L. Fabelinskiĭ's report* to be given today will show photographs of the Mandel'shtam-Brillouin doublet taken with a laser and distinguished for their striking sharpness. The speaker will also tell you how one can measure the viscosity of a medium and the dispersion of sound in it by measurements of this doublet. All of this is a further development of Mandel'shtam's ideas.

While Mandel'shtam was responsible for the groundwork in the theory of non-linear oscillations, as well as very valuable work in radiophysics, partly done along with N. D. Papaleksi, I shall not deal with them, not having enough competence in this field, but will go right on to quantum theory.

The Bohr theory of atoms, which was phenomenological to a considerable extent, was foreign in spirit to Mandel'shtam, and he didn't concern himself with it especially. However, 1.5—2 years after Schrödinger's first work on "wave mechanics" had appeared, Mandel'shtam jointly with M. A. Leontovich published a very important paper on the Schrödinger equation. The generality and depth of the stating of the problem that led him into this work was very

*See p. 637 of this issue.

characteristic of Mandel'shtam. As we know, in quantum mechanics the possible states of an elementary particle, e.g., an electron, are determined by the boundary conditions imposed on the wave function, such as the requirement that this wave function should remain finite out to infinite distances. He immediately called attention to the fact that this requirement needs further analysis and refinement. Here he started from the idea that a change in conditions, e.g., on Mars would have no effect on the behavior of an electron in the shell of an atom on earth. In the course of this analysis, Mandel'shtam and Leontovich were the first to develop the theory of the phenomenon now widely known under the name of the "tunnel effect." Later on, G. Gamow only had to apply this theory to the concrete physical phenomenon of radioactive alpha decay to obtain his results that have become classical.

In quantum theory, just as in other branches of physics, Mandel'shtam's attention was always drawn to the deepest, most fundamental problems. I have mentioned his studies, parallel with those of N. Bohr, but remaining unpublished, on the analysis and refutation of Einstein's paradoxes aimed at disproving the foundations of quantum mechanics. Now I wish to take up his final lectures on the fundamentals of quantum mechanics which he wrote in 1939, and which have completely retained their importance today.

I note in passing that in the late Thirties and early Forties Mandel'shtam gave several series of lectures at Moscow University that were outside the curriculum of the university. They were widely attended, not only by students and degree candidates, but also by all the physics instructors of the university and of many of the institutions of higher education in Moscow. These lectures were concerned with selected fundamental problems of optics, oscillation theory, relativity theory, and quantum mechanics. They were all distinguished for extreme clarity, distinctness, and depth. I am sure that it would be very useful to reissue them. They are to be found in the complete collection of his works, and have already become a collector's item.

Here I shall deal only with his lectures on the fundamentals of quantum mechanics, which bore the characteristic title, The Theory of Indirect Measurements. In these, he anticipated to a considerable extent the later stages in the development of quantum mechanics. Mandel'shtam started from the idea that the physical quantities dealt with in a theory have meaning only when fully-defined directions for measuring them experimentally are stated. For macro-objects, this measurement is realized simply; for example, the x coordinate of a body can be measured with a ruler taken as the scale. "However, since we are talking about molecular processes," he said, "such directions are unfulfillable in principle, rather than merely in practice .... Therefore, if I have called x a coordinate, I haven't established the relation of x to nature, but have only seemed to establish such a relation by referring to the macroworld. With such "definitions," theory is left hanging in midair. It would be better even to call x, e.g., a "quasicoordinate" than a coordinate.* Further on, he emphasized that the last link in the directions for measurement that we need is necessarily macroscopic, and therefore, direct measurements are possible only for free or almost free particles in weak fields. However, we need indirect measurements to study bound or interacting particles. "The principle of indirect measurement consists in the idea that we make a given system in which we wish to measure the quantity A interact with another microsystem on which we can make a direct measurement, and then we draw conclusions theoretically on the value of A."† Here wave mechanics operates with ψ-functions defining the relative probabilities of various quantities characterizing the given system. However, one can speak of probabilities only as applied to a set or "collectivity", which must necessarily be defined or isolated. "We have come to a point," said Mandel'shtam, "that I consider most essential and important. Namely, wave mechanics asserts that in order to define the micromechanical collectivity to which the ψ-function refers, it suffices to state (or fix) the macroscopic parameters."‡

I have briefly presented the content of only the introductory lectures of the series given by Mandel'shtam. However, it seems to me that one can see even from this how fully he anticipated the later stages in the development of the theory. Thus, his ideas anticipated the theory of S matrices (i.e., scattering matrices) developed twenty years later. This theory states that in studying an event of collision of elementary particles, the physical theory must be limited to describing only the actually observable phenomena, i.e., the relations between the parameters characterizing the freely colliding particles and the parameters of the free particles parting after the collision, without at all going into a detailed space-time description of this event itself on the small scale. Mandel'shtam's ideas are just as close to the later theories based on the fundamental uncertainty of the coordinates of elementary particles on ultra-small scales, as reflected in the non-commutativity of the coordinate operators.

I haven't taken up the problem of reviewing Mandel'shtam's contribution to science, even in the most general terms. I have only wished to illustrate the characteristic features of his creative work by

*L. I. Mandel'shtam, Polnoe sobranie trudov (Complete Collected Works), Vol. 5, AN SSSR, 1950, pp. 354-355.

†Ibid., p. 360.

‡Ibid., p. 356.

some examples.

In closing, I cannot but touch upon his personal qualities. Unfortunately, there are fewer and fewer people who knew him personally, who felt the irresistible charm of his personality, his unusually attentive relation to his students, whose personal initiative he encouraged in every way, and his human kindness in the highest sense of the word, combined with strict principle and inflexibility. He was truly a Man with a capital M.

Translated by M. V. King