Il'ya Mikhaĭlovich Frank (on his seventieth birthday)

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The outstanding importance of a scientist in the development of science becomes obvious to all if it is possible to indicate turning-point investigations that are inseparably associated with his name—studies that marked the beginnings of new trends and blazed new trails along which others rushed after him. The scientific works of Il'ya Mikhaĭlovich Frank meet this criterion beyond all doubt.

What comes to mind first is, of course, the appearance of the new field in optics and electrodynamics that is associated with Frank's name: the physics of the radiation of charged particles moving uniformly in homogeneous and macroscopically inhomogeneous media. The literature that has grown up here is immeasurably vast, the many varieties of other effects associated with these phenomena are diverse indeed, and their applications in experimental physics and even engineering are difficult to exaggerate. In this literature, the new ideas submitted and developed by Frank himself constitute a weighty contribution and have, in many ways, determined the present status of the problem.

But we also find works by Frank that lay the foundations in a totally different field of science—neutron physics—perhaps not as widely known and have not had as strong an influence on our understanding of general physical problems. Thus, Frank's name is inseparably associated with the origin, development, and use of the nonstationary-diffusion method, which has proven exceptionally productive.

It is natural that numerous students and colleagues should form "schools" about such a man. Frank's unique teaching style, which is based on encouraging self-reliance, his restrained and unobtrusive, but quite specific criticism and, above all, personal example—this style insured the success of the schools that were formed and the growth of some of his students into prominent figures (we note with sadness the premature passing of Fedor L'vovich Shapiro, Frank's closest and most outstanding student).

Frank was born on 23 (10) October 1908 at St. Petersburg. He entered Moscow State University in 1926. After graduation (1930), he worked for several years in A. N. Terenin's laboratory in the State Optical Institute (Leningrad), studying photochemical reactions by optical methods. His work in this area was marked by elegance and originality of procedure and exhaustive analysis of the experimental data. It formed the basis for the doctorate degree that was awarded to Frank at the age of 26.

In 1934, Frank transferred to the FIAN—the P.N. Lebedev Physics Institute, which had separated from the Physicomathematical Institute of the Academy of Sciences and was headed (and essentially reorganized) by S. I. Vavilov, moving later to Moscow with the Institute. Having a clear understanding of the significance of the "big" nuclear physics that was beginning to emerge at that time, Vavilov suggested to a group of young staff members, including Frank, that they turn their attention to this new field. Frank, an optics specialist by inclination, education, and working experience, agreed after some hesitation. This episode also illustrates Vavilov's remarkable qualities as a scientific organizer: in the interests of the matter at hand, he deprived himself of one of his most talented colleagues in his own research in optics.

With L. V. Groshev, Frank began an extensive experimental study of the recently discovered process of electron-positron pair production by γ-rays, completing it a few years later. It was studied in the gas of a Wilson chamber. There were no unexpected new discoveries, but the theory was confirmed with high accuracy.

It was at about the same time that P. A. Cherenkov began his famous studies of the emission of light by liquids under the action of radium γ-rays (a gram of radium was perhaps FIAN's major asset). Cherenkov, as is well known, observed that all pure liquids that he investigated emit faint light when exposed to γ-rays. At the time, the natural assumption seemed to be that this was simple luminescence. However, a series of experiments of different kinds convincingly established that the properties of the new emission were unusual. Vavilov showed that it is caused by electrons knocked out by the γ-rays and is not luminescence. Its nature remained a mystery until 1937, when I. E. Tamm and Frank gave an exhaustive explanation for this "Vavilov-Cherenkov emission" in a paper that has now become a classic.

For its time, the Tamm-Frank explanation was highly paradoxical. Everyone at that time seemed to be hypnotized by two conclusions from relativity theory, which were stated in widely used but inaccurate phrases: firstly, an electron cannot move faster then light and, secondly, a uniformly moving charge does not emit.

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It was necessary to overcome a high psychological barrier in order to understand that these phrases, which pertain to vacuum, do not apply to motion in a refracting medium. It is now difficult to imagine the opposition that had to be overcome. Frank was close to Cherenkov's experiments and correctly evaluated them as reliable. Here we have a striking manifestation of his characteristic openmindedness, his capacity for thorough physical analysis, attention to experiment, persistence in pursuit of a goal, his ability to single out the fundamental and decisive features of a phenomenon.

It is hardly necessary to dwell at length on the importance of this discovery. It marked the beginning of development of a new chapter in physics, which we might call the optics or electrodynamics of relativistically moving sources in refracting media. Not surprisingly, it was followed by the award of State Prizes to Vavilov, Tamm, Frank, and Cherenkov in 1946 and Cherenkov in 1946 and the Nobel Prize in Physics to Tamm, Frank, and Cherenkov in 1958 (Vavilov was no longer living). However, even without this reference to high official recognition, every physicist in the world is aware of the importance of this breakthrough in science.

But ever since, and now for 40 years, this entire area has been one of Frank's constant interests.

There is no doubt that the success of Tamm and Frank's truly joint effort was due in large part to the fact that each of the authors introduced his own style and his own approach to it. While Tamm preferred analysis by the direct methods of the Maxwell-Lorentz theory [cf. his paper in the Journal of Physics 1, 439 (1939)], the Fresnel-zone method was more attractive to Frank the optics specialist. He even solved the wave equation by decomposing the current of the moving charge into a system of radiating oscillators.

Operating with these methods, Frank then bought out many interesting features of the Vavilov-Cherenkov radiation itself (the duration of the flash, the role of the group velocity of light, radiation from moving sources with multipole moments, etc.). These papers present very clearly an approach based primarily on clear-cut physical notions and only to a lesser degree on the use of mathematical formalisms.

Frank then turned his attention to the study of other phenomena that are, of course, genetically related to the theory of the Vavilov-Cherenkov effect but form their own exceedingly broad and independent circle of problems. Thus, he considered aspects of the emission from a moving oscillator in a refracting medium (1942). This study ("the Doppler effect in a refracting medium") contained many results of both scientific and methodological importance.

His paper discussed an interesting model of the refraction and reflection of an electromagnetic wave at the interface between two media. When a plane electromagnetic wave falls on the interface, the point of intersection of the wave front (or the constant-phase surface) with the interface moves along the boundary at a velocity exceeding the phase velocity of the incident wave. The reflected and refracted waves can be treated as radiation from this faster-than-light source. This idea was redeveloped comparatively recently by V. L. Ginzburg, who noted that a source of radiation whose velocity exceeds that of light in a vacuum can be created in this way.

One concept that is highly important for the entire range of phenomena is encountered for the first time in this 1942 work. Analyzing the radiation of uniformly moving sources with the aid of the Huygens principle, Frank determined the path length at which, neglecting recoil, waves are emitted that add (when observed at a given angle) in such a way as to amplify one another. By analogy with diffraction theory, he called it the Fresnel zone. This quantity, which appears in a wide variety of cases of radiation from ultrarelativistic particles and was rediscovered by other authors many years later in a somewhat more general form (with allowance for electron recoil), now goes by a different name—the "zone of formation" or "coherence length." However, its content is essentially the same.

Frank returned again to problems that are related in one way or another to the radiation from an oscillator moving in a refracting medium. In particular, he analyzed the scattering of a plane electromagnetic wave by a particle moving in a refracting medium. In this study, he investigated features of multi-photon emission and absorption and derived the corresponding generalizations of formulas that had been derived earlier for the Doppler effect in refracting media.

Attention was shifted from all of these studies to a new problem that proved to be of unusual importance. A joint paper by Ginzburg and Frank discussed the field of a uniformly moving charge (a faster-than-light velocity is no longer necessary here) passing across a plane interface between two media with unequal refractive indexes. They found that electromagnetic radiation, which they called transition radiation, should be emitted here. It was not observed experimentally until the late nineteen-fifties, ten years after it was predicted theoretically.

Interest in this phenomenon grew steadily in the years that followed. The number of published theoretical and experimental papers devoted to it runs to over five hundred. After elaboration of many of its varieties, this phenomenon became perhaps as important as the Vavilov-Cherenkov effect. We are concerned here with a large new area. It was found that the transition radiation can serve as an effective tool for determining the optical properties of inhomogeneous media and their surfaces and for determining the parameters of the radiating particles, for example the energy of the moving charge.

In many respects, we owe our understanding of the basic features of radiation in inhomogeneous media, especially stratified media, to I. M. Frank, whose studies produced simple and general explanations.

Of no lesser importance than the concrete results of this entire broad complex of Frank's studies is the consequent unified physical understanding of a group of processes so varied in their nature and manifestations.

To this day, Frank maintains an active interest in the problems of electromagnetic radiation and the optics of uniformly moving charged particles, directing experimental research at Dubna on the transition radiation of very high energy protons and electrons.

Some stretching is obviously necessary to relate all these studies to nuclear physics, the field to which Frank was at one time urged to transfer by S. I. Vavilov (although both the study of electron-pair production in the field of heavy nuclei and the studies of radioactivity, which we have not mentioned, and the organizational activity of this period, to which we shall return again, constantly held him in the range of interests associated with nuclear physics). However, this transfer nevertheless took place, for the most part during the war. During the last three decades, Frank's activity has been concentrated basically precisely on this field, a totally new one for him, and specifically on the neutron and nuclear physics of low energies.

Frank organized (1946) and directed the Laboratory of the Atomic Nucleus in FIAN (which is now part of the USSR Academy of Sciences Institute of Nuclear Research), and organized (1957) and directed the Neutron Physics Laboratory of the Joint Institute of Nuclear Research at Dubna. From 1946 through 1956, he also headed the Radioactive Emissions Laboratory of the Moscow State University Scientific Research Institute of Nuclear Physics. Back in 1943, Frank had become heavily involved in work on problems posed by the need for crash implementation of the atomic program. One of the most important problems at that time was to determine as precisely as possible the fundamental neutron-physical parameters of uranium-graphite lattices and to establish the physical laws of neutron transport in such lattices. With a group of his comrades and students who had worked in his laboratory at the FIAN, Frank successfully solved a number of complex and interesting theoretical and experimental problems. The experimental studies were carried out by the generally accepted methods known since the work of Fermi and his colleagues, which were based on measurements of the spatial distribution of neutrons emitted by a stationary source. Valuable results were obtained here in a study of the thermal neutron utilization coefficient (i.e., the probability of escaping absorption in the moderator), the role of the air gap and water layer between the uranium and the moderator that are needed to cool the reactors, and the influence of moderator and uranium temperatures.

However, only rather limited information can be obtained from stationary-source experiments. For example, they cannot be used for separate determination of such important parameters as the average diffusion coefficient and the average lifetime of neutrons in matter. The measurements yield only their product. Important new ideas were needed, and they were forthcoming.

Frank showed that experiments with pulsed neutron sources may prove highly effective for such studies. The corresponding experiments were carried out under Frank's supervision at FIAN in 1954 and demonstrated the high effectiveness of the pulse method. In particular, they resulted in observation of the dependence of the average diffusion coefficient on the geometric size of the mass being investigated.

Using a simple and lucid two-group model of neutron diffusion, Frank showed that because of the difference in the rates of leakage of neutrons with different energies, the equilibrium neutron spectrum established in a volume with finite dimensions differs from the Maxwellian spectrum: it is richer in the least mobile neutrons. This effect is known as "diffusion cooling." It was also found possible to use pulse experiments to measure the parameter characterizing the deviation of the neutron spectrum from Maxwellian (the coefficient of diffusion cooling).

Thus, the pulse method proposed by Frank for the study of thermal-neutron diffusion was found to be much more informative and to require a much smaller amount of the substance to be studied than the stationary-source methods used earlier. Accordingly, the pulse method soon came into general use and has now become the accepted method both for study of the diffusion of thermal neutrons in various substances and for solution of various applied problems (in nuclear geophysics, instrumentation, and other scientific and technical fields).

Another series of papers was devoted to experimental study of reactions involving light nuclei in which neutrons are emitted, study of the interaction of fast neutrons with tritium, lithium, and uranium nuclei, and study of the fission process.

Performance of these projects required development of several new and, at the time, subtle experimental techniques. For example, considerable difficulty was encountered in absolute neutron measurements and measurements of the effective cross sections of nuclear reactions for charged particles of very low energy (in the tens of keV). This series of studies, which Frank supervised, was distinguished by high precision, care, and polish. He also passed this style onto his students, who then worked independently in developing the research pathways that he had opened.

Still another new area was opened up in Frank's study of nuclear fission: study of fission under the action of mesons and high-energy particles. It was shown that when the nucleus is excited in this way, most of the supplied energy is expended in emission of neutrons, and the energy of the fragments is the same as in the case of small excitations. However, the fission becomes more symmetric, and a significant probability of emission of fast protons and α-particles appears.

In 1957, with organization of the Joint Institute of Nuclear Research, it was decided to create a Neutron Physics Laboratory around a highly original installation—a pulsed fast-neutron reactor (IBR). The organization and supervision of this laboratory were entrusted to Frank. The reactor was started up in

1960 and has been operated successfully and improved since then. The young international staff of the Laboratory under Frank's supervision (about 200 scientific workers from the USSR and other socialist countries) has convincingly demonstrated all the advantages of the new type of pulsed neutron source, and, in particular, its record-high (for repeating sources) luminosity, with the result that plans to build new pulsed research reactors were made in several other countries. Later, the use of electron accelerators (the microtron and then the linear accelerator) as neutron-burst injectors made it possible to improve the resolution of the IBR-based neutron spectrometer by more than an order of magnitude. Frank and his staff were awarded a USSR State Prize for this work.

During the past twenty years, the Laboratory has become one of the world's major centers for neutron studies in nuclear, elementary-particle, and solid-state and liquid-state physics, biology, and radiation medicine. The great service rendered by Frank was his involvement of many institutes of the Academy of Sciences, the Academy of Medicine, and Joint Institute of Nuclear Research member countries in collaboration on these studies.

The Laboratory has now completed construction of the new IBR-2 reactor, which has a neutron flux two orders of magnitude higher than the first, and is starting it up with Frank's direct participation. It will support implementation of the scientific program for the next 15–20 years.

Among the experiments performed with the IBR reactor, we might mention the acquisition of new characteristics of neutron resonances (compound states of nuclei), magnetic moments, α-widths, etc., including experiments with polarized neutrons and polarized nuclear targets and a number of studies in the physics of condensed media.

Studies of ultracold neutrons (UCN) which were first produced experimentally on this reactor 10 years ago, were greeted with special interest. The specific properties of UCN have attracted the attention of many Soviet and foreign laboratories. Accordingly, Frank published several papers in which he analyzed, from the theoretical standpoint, the optical properties of UCN, aspects of their behavior in neutron guides, and the possible causes of the shortening of UCN lifetimes in closed spaces.

Study of reactions involving light nuclei and fast-neutron research are also being continued at the Neutron Physics Laboratory at Dubna and the USSR Academy of Sciences Institute of Nuclear Research Laboratory of the Atomic Nucleus.

Frank has always devoted and continues to devote much effort to scientific-community activity. Back before the war, when he was Scientific Secretary of the USSR Academy of Sciences Commission on the Atomic Nucleus, he took an active part in the organization of conferences. After the war, as a member of the Scientific Council of the President of the Academy, he gave a great deal of attention to the coordination of research on nuclear reactions in the Soviet Union, and is head of the steering committee of the All-Union Conferences on "Nuclear Reactions at Low and Medium Energies" and so on. It is impossible to list all obligations of this kind that he has accepted. He taught for many years at Moscow University, where he was a department head. His lectures on neutron optics at the International School of the Joint Institute of Nuclear Research, which is conducted under his supervision, have won wide recognition.

But the image of Frank as a scientist would be incomplete without mention of his scientific-literature activity. He approaches each paper devoted to the history of science or to the popularization of physics with an extremely responsible attitude. The resulting articles are brilliant in form and invariably contain interesting thoughts; examples are the long paper on Marie and Pierre Curie (the foreword to the book by the Joliot-Curies), his papers on S. I. Vavilov, and others. Popular articles and public lectures on nuclear physics and atomic energy, on the transition radiation and the Vavilov-Cherenkov effect, on the matter-light-particle relationship, etc. are never, to him, tasks to be avoided. Clarity and instructiveness are the basic attributes of these widely known efforts.

The picture of a scientist with his own special style of work emerges from all of the above. He should probably be regarded first of all as a subtle, thoughtful, and inventive experimenter who secures absolutely reliable results. At the same time, his thorough understanding of physics as a whole and his confident mastery of the necessary theoretical apparatus make this narrow characterization inadequate. After all, his work on charges and multipoles in uniform motion in homogeneous or inhomogeneous refracting media are studies in the theory of the processes. Indeed, even in neutron-nuclear problems, it is evident from the examples given above that much of his work was devoted to theoretical analysis. But in both experiment and in theory, Frank is first of all a physicist in general, an investigator who thinks clearly and precisely, does not fit a pattern, and is therefore capable of great accomplishments.

That which Frank has accomplished in science has brought him merited, widespread, and profound admiration. It comes from quarters far beyond the circle of his numerous students and friends. Therefore, the good wishes that will converge upon him on his birthday will be warm and heartfelt. The authors of this paper enthusiastically extend theirs.

Translated by R. W. Bowers