*THE DEVELOPMENT OF S. I. VAVILOV'S WORK IN PHYSICS**

V. L. LEVSHIN, A. N. TERENIN, and I. M. FRANK

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1. INTRODUCTION

S. I. VAVILOV, as is well known, had a very wide range of scientific interests. It would be a hopeless task to try to give in one report even a brief description of all that he did. Therefore we concentrate our attention on the development of those ideas most closely connected with Vavilov as a scientist and physicist. Foremost among these are questions of physical optics, namely the study of the nature of light, and of luminescence in particular. Closely associated with these is his work on the Vavilov-Cerenkov effect, to which attention will also be given.

Vavilov's scientific activity began more than forty years ago and was cut short in 1951. Ten years have already passed since that time. Given the contemporary rapid tempo in the evolution of physics, this period to a considerable degree already belongs to the history of science. The physicist now rarely reads articles published ten, not to mention twenty or thirty, years ago. This does not in the least mean that all the work done then has lost its value, although much of such work is short-lived.

Turning to the works of outstanding scientists, we find in them assertions which physicists in the future will consider familiar and obvious. We can follow also the development of those fields of science which were initiated by a given scientist. The scientist's work generates research in the same or related areas; the stream of such works not only makes its contribution but often essentially compels a reexamination of the initial points of view.

Thus a part of the results become generally known and can be found anywhere, and in order to move further, conclusive data and new ideas are needed. Therefore the initiator's own works in this or that scientific field often quickly become the heritage of the physics historian.

There are exceptions, however. We can take pride in the names of the scientists whose writings, published posthumously by our Academy, become reference manuals indispensible in present work. This applies to the writings of S. I. Vavilov. His books and articles are, as in the past, of current interest to a wide circle of readers and especially to physicists working in optics and luminescence.

*Report read by I. M. Frank on March 24, 1961 at the session of the U.S.S.R. Academy of Sciences Presidium devoted to the memory of S. I. Vavilov.

The sphere of ideas which were Vavilov's point of departure, his method of posing problems, and those questions to which his work was devoted have not lost their importance. The fact is that the subjects of Vavilov's studies were never chosen accidentally. They are organically connected with the definite group of essentially important problems which interested Vavilov throughout his scientific career. He formulated and refined his viewpoints on these fundamental problems over the course of many years. Vavilov would not have been an outstanding physicist if the concepts developed in such a lengthy and purposeful labor had lost their value during a short period of time.

2. S. I. VAVILOV'S WORK IN PHYSICS

In the last year of his life Vavilov wrote the book "The Microstructure of Light." In it he summarized and critically examined the results of several phases of his thirty years of work. The fact that many studies made over the course of his entire scientific career became an organic part of this book means that Vavilov's basic scientific interests really remained unchanged and that his works are associated in a profound community of ideas. In the preface to "The Microstructure of Light" Vavilov himself speaks of the unifying factor in these works. In brief, one can say the following: For practical purposes, "any source of light, any light flux can be described by three features: the energy of the radiation, the spectrum, and the state of the polarization." However, in reality these are only average, macroscopic characteristics. Behind them is concealed the exceptionally complex world of micro-optics, out of which such secondary features are constructed. In order to investigate the nature of light and uncover the relation between its properties and the properties of the elementary radiators which generate it, we must penetrate into the world of micro-optics.

By way of explanation, let us turn to investigations of the quantum fluctuations of light carried out by Vavilov and his collaborators using the visual method. These are the subject of the first part of "The Microstructure of Light."

Each light source visible to the human eye in reality contains an enormous number of separate radiators. These radiators—molecules, atoms, and electrons—are in motion inside the matter. The random motion of such elementary microscopic radiators and the discontinuity of the process of light emission by them, which is connected with the quantum nature of light, lead to the conclusion that fluctuations in the intensity of the light flux must be observed. How is this manifested in the properties of light and how can we judge the nature of the elementary radiators from these properties? So the problem is posed in the works of S. I. Vavilov. It is clear that the smaller the number of radiators making their contributions to the observable light flux, the larger will be the relative contribution of each of them. Therefore to clarify these questions it is necessary to carry out an experiment with extremely small light intensities. If it is a question of using visible light, the difficulty of devising an exceptionally sensitive light collector arises at once.

The solution of this problem was aided by Vavilov's deep interest in the study of the human eye, which possesses under certain conditions a remarkable sensitivity to light. The presence of a sharp threshold at which perception of light by the eye commences allowed Vavilov and E. M. Brumberg to work out and introduce into laboratory practice the photometric or "extinction" method. The human eye is used here as a physical device for measuring limitingly small light intensities. At that time this was the only method applicable for such purposes. It played a great role both in investigating the quantum fluctuations of light and in discovering the Vavilov-Cerenkov effect.

Physical optics and the physiology of vision are very closely interconnected in the exceptionally interesting experiments carried out by Vavilov and his collaborators on the fluctuations of visible light. It is rather to the physiology of vision that we must relate N. I. Pinegin's precise measurements of the threshold number of quanta under various conditions (carried out at the State Optical Institute) as well as Academician A. A. Lebedev's deliberations regarding the resolving power of the eye.

As regards the physics of fluctuations of light flux, this has been further developed by the Hungarian scientist, Prof. Janossy. Lately he has performed very delicate experiments which required the application of modern measurement techniques and would not have been possible using visual observation.

Very great progress has now been attained by experimental technology. Whereas earlier the detection of quantum light fluctuations was an extremely difficult problem, today using contemporary devices (photomultipliers) they are observed in everyday laboratory practice. Quantum fluctuations appear especially graphically in E. K. Zavoĭskii's experiments with electron-optical systems. This illustrates one of the features of modern physics. Often that which at the moment of its discovery lay on the margin of the experimentally possible, becomes after a short period of time generally practicable or even enters into the technology. Something similar has occurred with Vavilov-Cerenkov radiation. At the time when this phenomenon was discovered, the experimenter had to spend hours in total darkness, for otherwise this glow could not even be seen, not to mention having its intensity measured. Now the bright, light blue glow in water caused by this radiation can easily be seen by anyone visiting an atomic reactor of the so-called swimming-pool type. In the atomic energy pavilion of the Achievements of the National Economy Exhibition, the excursion guides always direct the attention of visitors to this glow. Nevertheless, if Cerenkov had not then carried out his program of research based on Vavilov's ideas, this glow might now be considered as some form of luminescence.

Vavilov's scientific interests in the area of physical optics extended far beyond the boundaries of his own microoptics. These general problems of the nature of light are only partially included in "The Microstructure of Light." Moreover, he attached special importance to the experimental foundations of the principal basic hypotheses of physics. Let us recall, for example, that Vavilov's book, "Experimental Bases for the Theory of Relativity," published as far back as 1928, was not only the first but perhaps the only systematic exposition of the experimental facts on which Einstein's theory rests. Now must be added the experiments of A. M. Bonch-Bruevich, which were begun at the initiative of Vavilov and completed after his death. Bonch-Bruevich showed by a direct experiment the independence of the velocity of light of the velocity of the light source, which relativity theory requires. He demonstrated the equality of the velocity of light emitted by the edges of the solar disc, which are rotating in opposite directions.

At the center of Vavilov's attention throughout his life, however, were his investigations in the area of luminescence. Here the principal problems regarding the interaction between light and matter and its conversions are very closely bound up with problems of microoptics—with the elementary processes in the luminescent molecule and its interactions with the surrounding medium.

3. INVESTIGATIONS OF LUMINESCENCE

Vavilov is the founder of the Soviet school of luminescence and the originator of systematic study of luminescence in our country. The results obtained by him in this field are quite significant.

The investigation of luminescence has a considerable history, an immense amount of factual material having been accumulated over many years. However a large part of this material, generally that obtained by foreign scientists, was descriptive in nature: with such-and-such a substance under such-and-such conditions such-and-such a result is obtained. The work of Vavilov and his school is of an entirely different sort. Each study is set up for the purpose of solving some quite concrete problem which, as a rule, is of fundamental importance. Vavilov is interested, above all, in the mechanism of the luminescence process, in the general laws of this phenomenon, in the role of the medium surrounding the luminescent molecule, and also in the possibilities offered by the investigation of luminescence for studying this medium.

Almost all the work undertaken by Vavilov himself was devoted to photoluminescence, i.e., luminescence under the action of light. Moreover, he studied especially the luminescence of complex molecules in liquids. This phase of research was not chosen accidentally, of course, and it turned out to be very fruitful.

In addition to his own research, Vavilov stimulated the development of other phases of work related to luminescence. Understanding clearly the great practical value of investigating crystal phosphors, he not only aided the organization of these studies in every way, but he had considerable influence on the development of the crystal-phosphor industry in our country. About thirty years ago at his iniative, his student and beginning scientist V. V. Antonov-Romanovskii started his own research in this field. V. L. Levshin and S. A. Fridman worked in the same direction.

While Vavilov was still alive, a remarkable group of researchers in the crystal phosphors was formed in the U.S.S.R. Academy of Sciences Physics Institute. Research centers also sprang up in other localities, in Leningrad, Tartu, and Kiev. At present this work is carried out quite widely in the U.S.S.R. Other phases of luminescence—cathode luminescence, electroluminescence, the study of luminoscintillators—are now being successfully developed. The value of all these investigations, which in a number of cases have been coupled with the study of semiconductors, has been immense both from the scientific and the applied standpoint. Of the great army of scientists now working out the problems of luminescence, very many are either directly or indirectly the students of Vavilov or the students of his students.

Among Vavilov's works possessing direct and great practical value, his leadership in the development of the fluorescent lamp cannot be overlooked. It is unnecessary to mention here the economic value of fluorescent lighting. It is sufficient to say that at the end of the seven-year plan it will occupy the dominating position among light sources.

The methods of luminescence analysis developed and widely propagated by Vavilov have also been extensively exploited. It is hardly possible to list all the areas in which these methods of analysis are applicable, they are so numerous and diverse. The use of methods of luminescence microscopy, to the development of which Vavilov's student E. M. Brumberg contributed significantly, has gained great importance in biology and medicine.

One of the essential features of the scientific creativity of Vavilov as a scientist and patriot is seen in the development of this work, namely his striving to relate theoretical work to practical and national economic needs. It is difficult to enumerate all those branches of our science and technology to whose development Vavilov has made a very concrete contribution. Such, of course, are the optical industry, crystal optics, photography, stereo motion pictures, and many others. He has also made an immense contribution to the strengthening of the defensive power of our country.

When speaking of the development of luminescence, we will dwell mainly on the development of those phases of it which are most directly connected with Vavilov's basic research in this area. We will also consider the essential value of this work for the whole science of luminescence.

At the center of Vavilov's attention lay the problem of the light conversion mechanism, by which a quantum of light absorbed by a luminescent substance can be converted into a quantum of luminescent light. There is first of all the question of the probability of such a conversion, which Vavilov called the quantum yield of luminescence. The yield determines the energetics of the process. If the luminescence yield were small in all cases, as had been predicted up to the time of Vavilov's work, this would mean that the main part of the absorbed light energy was irreversibly dissipated in heat. In this case luminescent light sources would always have been economically inefficient. Vavilov has proven that this is not the case.

He reliably demonstrated for the first time, in 1924, that under certain conditions the quantum luminescence yield is very close to unity. The solution of this problem at that time presented condiderable difficulties.

In consequence, a problem of both fundamental and practical import arose: On which factors does the quantum yield depend? One of the most important factors turned out to be the wavelength of the exciting light. It was known in luminescence as the so-called Stokes Law, according to which the wavelength of the luminescence light must be greater than that of the exciting light. However, this law can be violated. Vavilov showed that a violation of the Stokes Law is always accompanied by a decrease in the luminescence yield. "Photoluminescence can maintain a constant quantum yield if the exciting wave is on the average converted into a wave longer than itself. On the other hand, the luminescence yield decreases sharply when there is a conversion from long to short waves"—such is Vavilov's assertion.

Vavilov's law has now become part of all manuals on luminescence. Vavilov not only indicated the region in which his law was applicable, but he also noted cases in which it must be violated, considering these to be of basic and practical interest. Violation may occur, for example, if excess energy is stored in advance in a given substance and the incident light acts only as a triggering mechanism. This is known to take place in certain phosphors in which a flash of visible radiation is obtained upon exposure to infrared light. It is not by accident that Vavilov's article, "The Principles of the Spectral Conversion of Light," published in 1943, which contains the formulation of Vavilov's Law, concludes with the words, "...the practical surmounting of Stokes' prohibition by preliminary excitation of matter will, no doubt, be the solution of one of the most difficult and important technical problems connected with light conversion."

The mechanism of luminescence in antistokes excitation and the laws governing it concerned Vavilov for many years. In the last days of his life he said that he had a number of new ideas which he planned to work out and put into the article then in press, "Causes of Reduction in the Luminescence Yield in the Antistokes Region." However the proofreading of this article, which was lying on his writing table on the day of his death, was not destined to be completed by the author.

Of course this line of work was not abandoned after Vavilov's death. Quite important results concerning the connection between the absorption spectra of molecules and luminescence spectra were obtained in recent years by B. I. Stepanov in Minsk; these have a direct bearing on the problem. Other physicists, the foremost being V. V. Antonov-Romanovskii and M. V. Fock, have also considered this problem theoretically. Extremely delicate experiments measuring the luminescence yield in antistokes excitation have been carried out by M. N. Alentsev. Much has become clear as a result of these works, but much yet remains to be done in the future.

The medium in which the luminescent molecule is located has a considerable influence on the luminescence yield. New data on these matters have been obtained recently by V. V. Zelinskii and others and by A. S. Cherkasov at the State Optical Institute.

The question of the influence of the medium on molecule luminescence in liquids can be turned around; the properties of the luminescence will then permit us to infer the properties of the solutions. Vavilov himself indicated that the luminescence of solutions is "a remarkable and almost irreplaceable means of studying the liquid state." He planned to devote a special monograph to the study of the viscosity of liquids using luminescence methods. Unfortunately this project remained unfulfilled.

The potentialities of the study of liquids are very closely related to another luminescence problem at the center of Vavilov's attention, the kinetics of luminescence.

A necessary feature in any luminescence is the presence in the luminescence mechanism of an intermediate state between the moment when the energy required to excite the radiation is supplied and the emission of the light. Therefore any luminescence necessarily possesses an afterglow of finite duration—a glow continues after the excitation has ceased. According to Vavilov, the duration of the afterglow in luminescence phenomena must considerably exceed the oscillation period of the light. This assertion, which now seems obvious to the physicist, was introduced for the first time into the definition of the luminescence process by Vavilov. How essential this was is shown by the fact that the absence of an afterglow made it possible to prove that Vavilov-Cerenkov radiation is not luminescence; in its turn this is determined by the kinetics of the process.

A large number of the studies of Vavilov, Levshin, and other co-workers and students of Vavilov's are devoted to studying the duration of glow and its attenuation laws; in a number of cases these have revealed the nature of the glow in the substance under study. The methods applied by Vavilov in these investigations are diverse. First, it is possible to observe the process of attenuation of the brightness of fluorescence directly using fluorometers.

Another extremely fruitful research method consists of studying those reactions in which the excitation energy is taken from the luminescent molecule, quenching the luminescence. Vavilov was occupied for many years with the study of such processes of luminescence extinction, which allowed him to find out much about the mechanism and to develop a theory of the phenomenon.

Vavilov's theory of luminescence extinction by impurity contaminants was perfected after his death by his student B. Ya. Sveshnikov. This Vavilov-Sveshnikov diffusion theory of luminescence extinction underwent thorough testing in subsequent years which completely confirmed its correctness. Work in this field is now being carried out under the direction of Sveshnikov at the State Optical Institute.

Great progress was achieved in the direct study of the kinetics of the luminescence process. Even in Vavilov's lifetime a number of phosphoroscopic devices were invented both for scientific work and for practical purposes by Vavilov in collaboration with Levshin and their students. The first fluorometers for measuring the duration of glow lasting on the order of billionths of a second were built by L. A. Tumerman and V. V. Shimanovskii and later by M. D. Galanin. It turned out to be especially difficult, however, to design an apparatus for investigating glows lasting from one hundred-thousandth to one hundred-millionth of a second. During recent years a series of new devices have been constructed, chiefly under the direction of N. A. Tolstoĭ and A. M. Bonch-Bruevich, which have solved this problem. The application of these devices to the study of various luminors has led to the discovery of a number of phenomena not previously known.

The excitation energy received by the molecule by no means always remains in it up to the moment of radiation. In certain cases it makes a considerable journey in the luminescent liquid, passing from molecule to molecule. The theory of such an energy migration was developed by Vavilov as a result of working for many years on the so-called "concentration" extinction and depolarization of luminescence. These studies were developed further, chiefly by Galanin at the Physics Institute. Sveshnikov and his collaborators at the State Optical Institute also obtained a series of important results in this area.

It must be observed that Vavilov's ideas in this field turned out to be extremely fruitful. The migration of excitation energy plays a very important role in the luminescence of organic scintillators, which are employed to detect ionizing particles in nuclear physics. This process may also be essential for understanding a number of biological phenomena, in particular photosynthesis.

When speaking of the development of Vavilov's work it is impossible not to mention the investigations of the nature of elementary radiators to which he paid great attention throughout his scientific career. In "The Microstructure of Light" this is one of the central problems. P. P. Feofilov at the State Optical Institute deserves great credit for the further development of this work. The so-called polarization diagram method proposed by Vavilov forms the basis of his investigations. If Vavilov considered this method as a principal means for studying elementary radiators, Feofilov accomplished its practical working-out. By this method he succeeded in discovering various types of electric and magnetic radiators and in determining their orientation in the crystals. He solved a number of very important problems by this method.

Another phase of this work, investigation of the so-called polarization spectra, is now being conducted by Feofilov at the State Optical Institute and by G. P. Gurinovich and A. N. Sevchenko in Minsk.

From the brief review presented here, we can certainly conclude that the fundamental lines of work developed by S. I. Vavilov have retained their current interest. The science of luminescence continues to develop extensively and productively in our country.

4. VAVILOV-CERENKOV RADIATION

Our survey would not be complete if it did not dwell on the development of work on the Vavilov-Cerenkov effect. At first glance the Vavilov-Cerenkov effect stands apart among the various phases of Vavilov's research. This phenomenon is now wholly linked with the physics of the atomic nucleus. Vavilov was always interested in nuclear physics. He understood the value of this field of science long before it became obvious to the average physicist. At his iniative studies along this line were begun during his time at the Physics Institute, although he himself did not engage in nuclear physics. Nevertheless, Vavilov's and Cerenkov's discovery was only at first glance accidental. It could hardly have been made in any other laboratory than Vavilov's.

In 1933 Vavilov proposed to his research student P. A. Cerenkov an investigation of the luminescence of uranyl salts under the action of radium γ rays. As much as five years before Vavilov and Levshin had studied the luminescence of uranyl salts under the action of light and compared this with the luminescence properties of the same substance irradiated by x rays. This complementary investigation of luminescence under the action of γ rays was not, of course, haphazardly undertaken. By obtaining the excited state of the same molecules using different methods (for example light, x rays, and radioactive radiations), the physicist acquires one more way of studying the excited states of molecules and the mechanism by which they are produced. Such a comparative approach was not chosen randomly by Vavilov. That this was also characteristic of P. N. Lebedev, whose student Vavilov was, cannot be ignored.

It is to be regretted that the investigation of luminescence under the action of radioactive radiations, begun at the iniative of Vavilov, was not expanded on the necessary scale during his time. We have already mentioned that Vavilov's ideas concerning the migration of energy now find fruitful application, and that the phenomenon itself is widely used in nuclear physics in the so-called scintillation counters.

Cerenkov's work on luminescence under the action of γ rays solved a restricted problem connected only with the luminescence of uranyl salts. The discovery at the beginning of this work of a universal, dark-blue glow which would come to be known as the Vavilov-Cerenkov effect compelled the complete concentration of the research upon it.

At the present time the explanation of the Vavilov-Cerenkov effect has already entered the popular literature. It suffices to say that a direct analogy exists between the light waves created by a moving electric charge in the Vavilov-Cerenkov effect and waves formed in water by the prow of a ship. Radiation of energy begins when the velocity of uniform motion exceeds that of wave propagation; consequently an additional force arises which slows down the motion. This is also now well-known and commonplace to us. In the case of an airplane we call this phenomenon the sound barrier.

We must keep in mind, of course, that this is only an analogy. Since acoustic and light waves are entirely different in nature, the phenomena generated by them will differ in major ways.

The development of experimental techniques has made possible in recent years the use of Vavilov-Cerenkov radiation to construct devices—Cerenkov counters—for recording high energy nuclear particles. Such counters make it possible to judge the velocity of the particles and, in some cases, their electric charge. These are new and very important means for investigating the nature of particles. It suffices to say that Cerenkov counters have been used in such notable discoveries of recent years as the discovery of the antiproton. Cerenkov counters are also being sucessfully applied to the study of cosmic rays on artificial earth satellites.

The wide application which Vavilov-Cerenkov radiation has found in nuclear physics led to the awarding in 1958 of the Nobel Prize to the remaining participators in this work.

Diverse uses have been found for Vavilov-Cerenkov radiation. We will dwell on only one of them, which is being successfully developed in our country, mainly by A. E. Chudakov.

In 1934 at the initiative of Vavilov, his young collaborators Dobrotin, Frank, Cerenkov, and Khvostikov began studying the glow of the night sky. The observations were made visually by the photometric extinction method. It soon became obvious that Vavilov-Cerenkov radiation produced by cosmic ray particles in the atmosphere must also make its contribution to this glow. Computation showed that the human eye could not detect it. Now contemporary experimental techniques make it possible not only to detect but also to use this phenomenon to study cosmic rays.

What happens essentially is that a fast cosmic particle entering the atmosphere can cause a shower of particles, which will be absorbed in the upper layers of the atmosphere. The burst of Vavilov-Cerenkov radiation produced by these particles will reach the earth, however, and can be detected. Thus Vavilov-Cerenkov radiation permits us to see, in the literal sense of the word, on the earth processes which are occurring in the upper layers of the atmosphere. It is a distinctive characteristic of the Vavilov-Cerenkov effect in gases that light is emitted almost exactly in the direction of motion of the particle, as if continuing its trajectory. Therefore, if some heavenly body is emitting γ rays, these may be detected by directing an optical system which records Vavilov-Cerenkov radiation at this heavenly body. Recently Chudakov and collaborators explored in this way the radiation from various sources of radio waves lying in the constellations of Cygnus, Cassiopeia, and Taurus. When aiming a Cerenkov telescope at the object Cygnus A, a small increase in the number of Vavilov-Cerenkov radiation flashes was detected. The experiment is very difficult and for the present is of a preliminary nature; additional verification is required. However, the possibility is not excluded that in the near future γ astronomy may take its place with the presently existing radioastronomy, the way having been opened by use of the Vavilov-Cerenkov effect.

It should be noted that the Vavilov-Cerenkov effect and allied phenomena are not only important for detecting nuclear particles, although these applications are very valuable. As V. I. Veksler first showed, the effect can be reversed, so that one can use it to accelerate nuclear particles. The use of the effect to generate radio waves is envisaged as well. This phenomenon also has considerable importance for that state of matter known to physicists as plasma. Plasma is of the highest value for a number of contemporary problems, in particular for controlled thermonuclear reactions. A series of studies, analyzed in I. E. Tamm's Nobel lecture, has been devoted to the problems of applying the Vavilov-Cerenkov effect in plasma.

The least studied and most complicated case of the Vavilov-Cerenkov effect, namely the case of radiation in optically anisotropic media, has turned out to be important in plasma physics. Its theoretical consideration was begun as far back as 1940 by V. L. Ginzburg, and because of its current interest a great number of the papers of Bolotovskii, Muzicar, Kurdyumov, Frank and many others have been devoted to this problem in recent years.

It must not be thought that the Vavilov-Cerenkov effect is unrelated to other problems associated with the radiation of light by fast particles. On the contrary, the study of this phenomenon has stimulated the study of a number of allied phenomena. For example, the radiation of an atom travelling with a velocity exceeding that of light has been studied; here quite surprising phenomena are bound to occur. It also turned out that when a light source is moving at even comparatively small velocities in a medium, the radiation frequency not only may undergo a Doppler shift, but may also be split into several components. It has been assumed that such a complicated Doppler effect will be observed in an atom travelling in a gas. Quite recently Barsukov and Kolomenskii showed that this phenomenon can apparently be observed in a completely different region, namely in the emission of radio waves by artificial Earth satellites travelling in the ionosphere.

There are other phenomena closely related to the Vavilov-Cerenkov effect to which many works have been recently devoted. Great attention is now being paid to the so-called transition radiation, whose theory was developed at the Physics Institute under the direct influence of work on the Vavilov-Cerenkov effect. This radiation is produced, for example, when a beam of charged particles strikes a metallic surface, i.e., in very many physics experiments.

It is comforting to note that in the development of the theory of phenomena associated with the Vavilov-Cerenkov effect Soviet science, as before, occupies a leading position. From this example it may be seen how fruitful the further development of work whose beginnings were laid down by S. I. Vavilov has been.

5. CONCLUSION

In our report we have touched on a number of different fields of work with which S. I. Vavilov's name is associated. This survey is, of course, far from complete. Even a complete catalog of the results obtained would be inadequate to describe Vavilov as a physicist. This is true not only because it is impossible to understand completely the activity of Vavilov the physicist if we do not examine his other fields of work, for example, if we omit the work of Vavilov the historian of science. All who had occasion to work with or under the direction of Vavilov know the exceptional value of his rare personal qualities, his marvelous memory, the width of his knowledge, the depth and amazing concreteness of his judgments.

Many characteristics of Vavilov the physicist can be understood without turning to personal recollections: They found their expression in his books. Among such books there is one which has always had an especially wide group of readers. It has already gone through eight editions in the Soviet Union and a number abroad, and undoubtedly will be reprinted in the future. This is the book, "Eye and Sun," which is brilliant in the form of its exposition and very profound in content. It is a rare example of a serious scientific book which is also accessible to the general reader, a model popular-science book. However it is also interesting because of the fact that many of the characteristic qualities of Vavilov as a scientist are revealed here with special clarity.

The subject matter of the book corresponds to what was principal in Vavilov's scientific interests. The nature of light, its radiation, and its action upon matter are questions examined in the book. Also at the center of attention are the peculiarities of the human eye. Characteristic is the amazing width in the treatment of the problems, where it is impossible to separate Vavilov the physicist from Vavilov the philosopher and expert in cultural history.

Vavilov's book is devoted to a broad range of natural phenomena, from astrophysics to the physiology of vision. His extensive interest in nature is not at all an objectless admiration of its beauties. It is, rather, similar to an interest in a fine and not yet completely read book. Speaking of books, it must be recalled that Vavilov was a profound connoisseur and great lover of books.

Vavilov's ability to bring into the discussion everything necessary to explain the problem, even that which is far removed from physics, is remarkable. Considering the evolution of concepts of light and vision, he turns to the verses of Pushkin, Fet, Tyutchev, and Esenin. Those who love to discuss physics and lyric poetry should perhaps read Vavilov. He was not, however, simply a connoisseur of poetry. Despite all the love for verses on the part of the author and readers, these quotations in a book devoted to physics would have been out of place if they had been presented merely for the sake of color. Here, of course, not only artistic value but the ability of the genuine poets to perceive and comment on a new idea with astonishing accuracy is what is important. Therefore when speaking of what vision gives to man it is impossible to overlook the words of the poets about light and the sun.

It is probable that his clear understanding of the history of science and the whole complexity of real natural phenomena often compelled Vavilov to caution his students against hasty enthusiasm for the various scientific fashions, and especially against elevating them into something final and infallible. However, he was the first to discover something new in the great flux of scientific literature and point it out to his students.

Recalling now Vavilov's work in the laboratory, one is struck by one of his amazing abilities. With all his tremendous busyness he never was in a hurry, and he found it possible to allot what seemed an unlimited amount of time to each person who turned to him. In his conversations he spoke in detail of the literature news, divided his considerations among very diverse matters, and helped everyone willingly both with advice and acts. For all those who had the occasion to work closely with Vavilov, his personal example was of enormous value. It is difficult to imagine a better scientific guide.

Observing today the seventieth anniversary of the birth of Sergeĭ Ivanovich Vavilov, we think with love and deep respect of this remarkable scientist and man.

Translated by Mrs. J. D. Ullman