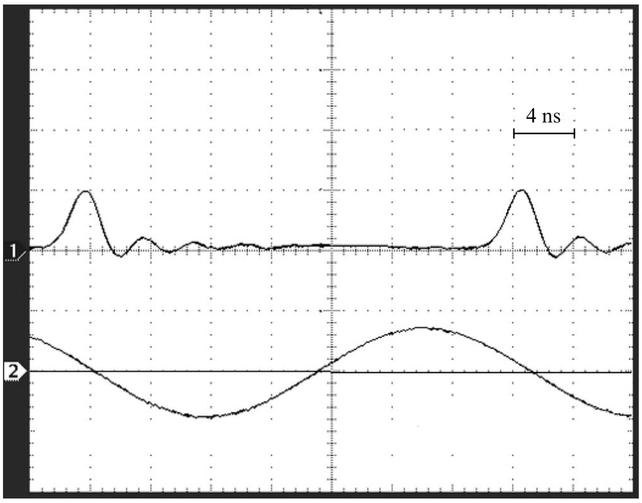

Figure 10. The noise-suppressed signal extended in time.

5. Conclusions

In this work, we directly measured for the first time (to the best of our knowledge) the speed of the light emitted by an ultrarelativistic source. The results obtained here are incompatible with the Ritz ballistic hypothesis which implies adding the speed of light to the light source velocity. It is shown that inserting a glass plate into the light beam does not affect the speed of its propagation to within fractions of a percent, whereas, according to Ritz's hypothesis, the speed of light after its passing through a fixed window should decrease by a factor of 2. The measurements of the speed of light pulse in a vacuum yielded a value differing from its table value by less than 0.5%. The results of the measurements can be considered as the most straightforward evidence of the validity of the STR second postulate.

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Sergei Ivanovich Vavilov as a historian of science

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1. Introduction

"One can hope that the history of science will sometime itself become science. A warrant of this is the obvious growth of natural science and technology and hundreds of thousands of people creating the history of science on the globe in our sight. It is impossible to ignore this powerful natural phenomenon

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which is capable of changing the Earth no less drastically than earthquakes and floods do'' (S I Vavilov [1], pp. 3, 4).

In the Soviet period, along with the rapid growth in physical studies, the literature on science history, which was first created by physicists themselves (P P Lazarev, V K Frederiks, A N Krylov, S I Vavilov, et al.), also grew quite rapidly. The work of A N Krylov and S I Vavilov devoted to Isaac Newton, including translations of his *Principia* and *Opticks*, corresponded to the highest professional level of historic scientific studies. This work formed the basis for the professional history of physics (at the Institute of the History of Science and Technology in Leningrad and at the Department of Physics of M V Lomonosov Moscow State University). However, the institute in Leningrad headed by N I Bukharin was closed after a while, and the second wave of the institualization of the history of science and technology took place in the postwar years. The Institute of the History of Natural Science and Technology of the Academy of Sciences appeared in Moscow during this wave.

Notice that S I Vavilov played a key role (organizational and conceptual) in the formation of the professional history of science, in particular, physics, both in the prewar and in the postwar periods. Some of his studies are still archetypes of historic scientific studies (Vavilov's book about Newton and the series of his works on the history of optics in the 17th–18th centuries). They contain certain general concepts about the structure of physical knowledge and its development; the relationship between an experiment, the physical foundations of a theory, and its mathematical apparatus; mechanisms of the appearance of a new scientific knowledge and its interaction with social institutions, etc. It is such a scope of concepts that we will call the historiographic concept.

We will consider in our report the historiographic concept of S I Vavilov, whose name was given to the Institute of the History of Natural Science and Technology, RAS not by accident. Beginning from the 1920s and especially from the early 1930s and to his last days, Vavilov combined in an extraordinary way huge organizational and research activities in the field of optics with investigations into the history of physics. A brief chronological and bibliographic reference characterizing S I Vavilov as a historian of science is presented in the Appendix. [1]

2. Historiographic concept of S I Vavilov

''...The history of science can and must be the true and only 'theory of knowledge' instead of many artificial epistemological constructions...'' (S I Vavilov [1], p. 7). [2]

The key points of the historiographic concept of S I Vavilov were presented in a 1933 article ''Old and new physics'' [1] in the collection *To the Memory of Karl Marx* reproduced in the collection *The History and Methodology of Natural Sciences* in 1965, and also in an article ''Physics'' in 1936 in the *Great Soviet Encyclopedia*, Vol. 57 [3]. [3] S I Vavilov's contemplations about the driving forces and basic processes governing the history of science often appeared in his diaries as well, to which he made entries each free minute.

Vavilov's historiographic concept can be approximated by the following points.

(i) The history of science must tend to become science, not in the sense of its reduction to 'naive' logical schemes withdrawn from the live human and social and cultural context, but rather in the sense of some synthesis of sciences of natural and humanitarian cycles taking these contexts into account.

(ii) Among the numerous factors determining the subject-matters and specific features of the development of science, there always exist a small number of dominating factors. Their determination is one of the key issues of a historical scientific investigation.

(iii) ''The continuous line of the development of science contains some 'singularities', which look like turning points in history,'' 'scientific upheavals' of a certain type or scientific revolutions, although the latters (unlike the approach of T Kuhn) follow the concept of the continuity of scientific development.

(iv) The consistent historiographic concept should comprise the description of the process of reception of a new scientific knowledge; only this process can explain the succession and continuity of the development of scientific ideas and theories.

(v) The historical experience acquired from physics teaches that theories are the fundamental systematic units of scientific knowledge and that there are three basic methods of their construction (at least in the field of exact natural science): the method of hypotheses-models, the method of principles, and the mathematical hypothesis method.

(vi) The true theory of knowledge and philosophy of science should be based on the history of science (or even more bluntly, they are themselves the conceptualized history of science or the theoretical historiography of science).

3. The history of science must tend to become science

''...The history of science is a necessary and maybe even sufficient prerequisite for planning science. Therefore, sooner or later the history of science should become science'' (S I Vavilov [1], p. 4).

The history of science has grown and become a large special field; however, the problems indicated by Vavilov are still urgent. We will describe them briefly, giving the floor to S I Vavilov himself. Below, we present a mosaic of citations with brief comments.

On the scientific nature of the history of science and planning science based on it: ''To understand this process (the growth of natural science and technology — *Authors*), as always, means to master it in many ways and to learn to direct it in the required direction. The history of science is a necessary and maybe even sufficient prerequisite for planning science.'' [1, p. 4]. Unfortunately, despite progress in the history of science, Vavilov's rather cheerless evaluation of the state of this field of knowledge still remains valid to some degree: ''To the present time, it (the history of science in the early 1930s — *Authors*) rests, however, in the cradle of personal characteristics and biographies, chronological dates and, in many cases, quite imperfect documentation.

[1] A brief essay on the historiographic concept of S I Vavilov was published earlier in Ref. [2].

[2] By the way, remarkable article [1], from which this phrase is taken and which is one of the most conceptual works on the history of science, was not included at that time in the *Collected Works* of Vavilov, maybe because of this phrase.

[3] References to pages in paper [3] and other papers included in the *Collected Works* of Vavilov are given according to this collection. References to pages in article [1] are indicated for its reprint in an MSU collection published in 1965.

'The scientific nature' of this history is reduced to naive schemes, in which science is withdrawn from a live changing medium and is treated as an autonomous organism following almost a logical harmony in its development'' [1, p. 4].

Such was Vavilov's vision of the 'scientific visage' of the history of science. The transformation of the history of science to science itself would allow us to predict and plan the development of society, which was considered in the early 1930s as the most urgent issue in our country, which had to be solved based on a scientific foundation. And therefore, science itself should be planned. The latter, according to Vavilov, is possible only based on the study of the historic scientific experience, which should be brought to the scientific level.

But Vavilov warned against a hasty solution to this problem by 'withdrawing' science from the social and cultural context and constructing 'naive' logicized schemes. It seems that Vavilov saw the 'historic scientific nature' of the history of science as a synthesis of the natural science and humanitarian scientific approaches. Therefore, a certain union should exist between scientists working in the field of natural sciences and humanitarians (historians, philosophers, sociologists) to elaborate a certain form of the historic scientific professionalism for solving the problem of the scientific nature of the history of science.

However, instead of this union (which was in fact unreal at that time in the USSR because of the catastrophic degradation of humanities), a vast gap existed between natural and humanitarian sciences, the history of science vexatiously being somewhere in between (''the subject itself was unclear and alien'' for historians, while natural scientists ''had no time to look back'' and ''in many cases... they did not have the necessary general historic and philosophic knowledge''). Then, Vavilov specifies a number of fundamental questions on the relation between science and prescientific and nonscientific knowledge, which have been considered but nevertheless have not been solved to date.

''Science as a historical factor'' is another important issue in the history of science put forward by S I Vavilov. This question is closely related to another basic issue of historic scientific study — the determination of the driving stimuli of science development. Vavilov points out that ''the inner logic of science itself was considered consciously or unconsciously almost the only such stimulus'' [1, p. 6]. However, as he shows by the example of optics in the 17th–18th centuries, ''it is reasonable to seek such stimuli in the technical challenges of the time, in the social and economic conditions of people and times, etc.'' [1, p. 6]. At the same time, ''it would be erroneous to try to find a detailed parallelism between the history of science and the history of society'' (*ibid.*). ''Social and economic factors are the main catalyst of the development of science, but these processes begin from the level that science has already achieved'' [1, p. 6]. Beginning from the 16th century, this level is maintained at ''a certain height'' owing to the ''international scientific relations.'' The questions about the history of science formulated by S I Vavilov in the early 1930s still remain urgent.

4. Definitive ''factors of the kinetics of science development.'' Galilean and Newtonian telescopes

S I Vavilov believed that, despite the progressive and cumulative nature of the development of scientific knowledge, ''the course of science is not one-dimensional, possessing a 'width', bifurcations, zigzags, and loops'' [4, p. 235]. He protested against the reduction of the live, multidimensional, and multifactor kinetics to the one-dimensional mode repeating ''the time-swept inner logic of today's scientific dogma,'' but ''rarely coinciding with intricate zigzags actually happening'' [4, p. 235].

However, Sergei Ivanovich could distinguish some dominating factors in this intricate multifactor process. For example, one such dominant factor in the development of optics, mechanics, and physics as a whole in the heroic epoch of Kepler, Galileo, and Newton in the 17th century was the telescope. ''*Siderius Nuncius*'' (*Star Herald* by Galileo, in which he describes his applications of a telescope — *Authors*) wrote S I Vavilov, ''compelled the scientific world in the early 17th century to engage in research on dioptric devices, the grinding and polishing of glasses. The history sees Descartes, Spinoza, Newton, kings and princes, abbots and monks, physicists, philosophers and physicians engaged in this activity. This resulted in a very rapid development of the geometrical optics of refracting media, glass machining technologies, the art of construction of optical devices and optical manufacturing in a broad sense'' [4, pp. 236, 237]. In another paper, Vavilov distinguishes the same factor which became the key stimulus of the entire creativity of Newton. ''The source of the scientific activity of Newton, in which the three main channels — optics, celestial mechanics, and mathematical studies — are intersected, is a reflecting telescope.'' And then he explains this 'formula': ''The search for the perfect shape of optical glasses... is a probable practical motive for the first geometrical works of Newton. The discovery of light dispersion is a direct consequence of work on the improvement of telescopic glasses. The objects of telescopic observations — planets and their satellites — attracted the attention of Newton to celestial mechanics. Finally, the initial aim of prolonged chemical investigations... was to find alloys suitable for manufacturing metal mirrors for reflectors.... Thus, it is reasonable to assume that the external motive (for the development of Newton's investigations — *Authors*) was a technological problem of the refinement of telescopes'' [5, p. 109]. After one and a half decades, S I Vavilov transferred this key thought to his book on Newton, comparing the Newtonian telescope to an overture: ''Just as in an overture preceding a large musical piece the main motives of this piece are interlaced, so in the Newtonian telescope we can see the sources of almost all the main avenues of Newton's scientific thinking and work'' [6, p. 321]. In other cases, S I Vavilov could also distinguish similar key factors governing the choice of the topical scientific problem and the creation and further development of scientific ideas and constructions.

5. ''Singularities'' in the ''continuous line of the development of science''

Accepting the unidirectional progress in the development of science, Vavilov assumed that this growth is not quite continuous and ''the continuous line of the development of science contains some 'singularities', which look like turning points in history'' [1, p. 7]. This approach anticipates the concept of scientific revolutions by T Kuhn, which became popular in the 1960s–1970s. By the way, Sergei Ivanovich used a similar term — 'scientific upheaval'.

Attentive reading of his works devoted to Newton and Galileo allows us to understand the peculiarities of the scientific revolution in the 17th century and some specific features of 'scientific upheavals'. Vavilov believed that one of them was the quantum-relativistic revolution beginning at the end of the 19th century and spreading over the first third of the 20th century. According to Vavilov, the most important among the scientific revolutions belongs to the radical transformation of the fundamental theoretical system of concepts, allowing a more detailed and accurate description of the accumulated experimental material. He emphasized that the roots of revolutionary transformations 'extend far back' and that new theoretical approaches are "the necessary result of the preceding development, spectacular in its ripeness and fruitfulness, but in fact not containing anything qualitatively new" [1, p. 7]. However, it is not easy to agree entirely with the latter statement, which, of course, differs from Kuhn's concept of the scientific revolution [7]. Vavilov believes that the discontinuity aspect obeys the continuum of scientific development, as 'singularities' are the solutions to differential equations, which are continual by their nature. S I Vavilov, giving Newton's predecessors their due, showed the novelty and depth of Newton's breakthrough. This also concerns the quantum-relativistic revolution, although he considered it necessary to reveal classical sources of quantum and relativistic ideas.

6. "Inculcation of the scientific truth"

For a scientific discovery and a new scientific theory to be established in science, it is insufficient to make or construct them, because they should also be accepted by the scientific community. The historians of science only comparatively recently understood the importance of the problem of reception of new scientific knowledge. Thus, a comprehensive study of the reception of the theory of relativity by scientific communities in different countries [8] first appeared only in 1987.

S I Vavilov well understood the importance of this aspect of a historic and scientific study. However, instead of the reception he talked about the 'inculcation', which resembles the assimilation of the results of fundamental studies in practice and technologies. Thus, he said that Galileo possessed the amazing gift of what is now called "the inculcation of the scientific truth." "The truth," he continued, "became the public domain owing to its application, new arguments clear to everybody, due to the active struggle for it..." [4, p. 236]. In his paper on the optical works of Lomonosov, S I Vavilov talked about his tragedy because the rich scientific legacy of Lomonosov "is buried in unread books, unprinted manuscripts, and abandoned and ruined laboratories on Vasil'evskii Island and on the Moika" [9, p. 168].

Sergei Ivanovich noted that the remarkable optical discoveries of Leonardo da Vinci also had the same destiny [4, p. 250].

7. Three main methods for constructing physical theories

The study of Newton's works, the history of optics, and the history of the theories of relativity and quanta being created before his eyes led S I Vavilov to the following classification of the main methods for constructing physical theories: the method of hypotheses-models, the Newtonian method of principles, and the Maxwell mathematical hypothesis (or mathematical extrapolation) method. Vavilov wrote already about the Newtonian method of principles in 1927, showing that his *Opticks* and *Principia* are based on this method opposing the hypothesis-model method, which was popular at that time [5]. However, the latter should not be understated: "Based on the model hypothesis method, the classical theory of heat, light, sound, etc. has grown" [3, p. 156]. The advantages of this method are its clearness and 'intelligibility'. Its limitation lies in the unsubstantiated extrapolation of the macroscopic (human) scale to the microworld.

Vavilov considered principles used in the 'method of principles' as "the ascertaining of an experiment in the adequate mathematical form" [3, p. 156]. "Such principles, mathematically expressed and generalized, play further the role of axioms in geometry, from which logical conclusions are made concerning specific physical problems" [3, p. 157]. The examples of theories constructed by this method are not only the classical mechanics of Newton or his optics, but also classical thermodynamics and the special theory of relativity. The reliability and viability of theories constructed by this method is confirmed by the entire experience in the development of physics. Compared to the model hypothesis method, this method is considerably more abstract and less clear. The common feature of both methods is that "mathematics plays... mainly a service, technical role" in them [3, p. 157].

In the mathematical hypothesis method, which is "the most abstract and detached from experience," but is "very important in modern physics" [3, p. 157], mathematics plays a completely different, creative, heuristic, structure-forming role. Vavilov himself never used this method, but well understood and highly appreciated it. According to Vavilov, "this method was first used by Maxwell with remarkable success in the field of electrodynamics" [1, p. 11], and after that "mathematics acquired incomparably deeper significance for physics." "Mathematics was transformed from an auxiliary tool for quantitative calculations and formulations to a heuristic method allowing a theorist to anticipate experiments..." [1, p. 11]. The creations of the general theory of relativity and quantum mechanics are, in the opinion of Vavilov, "amazing examples of the power of the method of mathematical extrapolation" [1, p. 11].[4] Vavilov highly appreciated the mathematical hypothesis method and believed that, apart from experiments, it should be supplemented or corrected by methodological regulators, such as the correspondence and simplicity principles [1, p. 12]. Admiring the latest amazing achievements of the general theory of relativity, quantum mechanics, and quantum electrodynamics, Vavilov wrote at the end of his remarkable article in 1933: "The theoretical method applied by Maxwell is infinite, like mathematics, and any scales arbitrarily distant from common human things pose no threat to it. Based on this method, physics can develop infinitely, relying alternatively on experiments and mathematical thought" [1, p. 12].

Vavilov believed that there is no insurmountable boundary between these theoretical methods. In the real work of a theoretical physicist, they are interlaced, passing

[4] According to Vavilov, "its essence consists... in finding such mathematical forms which, including all particular cases directly found in experiments, would provide simultaneously a considerably broader content. Certainly, the only justification of the correctness of the chosen mathematical form can be its subsequent confirmation in experiments. Deprived of concrete images and models in the new-scale world, a physicist has found in mathematics an infinitely capacious method for the development of a new theory" [1, pp. 11, 12].

to each other (see, for example, paper [5, p. 108]). In this way, the history of science gives rise to the live cognition theory and philosophy of natural science based on the experience of several generations of natural-science researchers and devoid of factitious epistemological schemes.

8. Appendix. S I Vavilov as a historian of science (chronological reference)

After 1922: Vavilov translated foreign books on the theory of relativity (A Einstein, F Auerbach). Vavilov made and edited many translations until 1951.

After 1926: Biographical articles and articles on physics in encyclopedias (78 articles).

1927: "Principles and hypotheses of Newton's optics" review in *Uspekhi Fizicheskikh Nauk* [5]. Later, Vavilov returned many times to the creativity of Newton.

1927: Translation of Newton's *Opticks* [10].

1928: Monograph *Experimental Foundations of the Theory of Relativity* with chapters inscribed with epigraphs from Newton's *Principia* and *Opticks* [11].

1933: Article "Old and new physics" [1].

After 1934: Chief of the section of the history of physics and mathematics at the Institute of the History of Science and Technology, the USSR Academy of Sciences (Leningrad).

1937: Article "Optical views and works of M V Lomonosov" [9].

After October 1938: Article "Science and technology in the French revolution period" [12].

1943: Biographic book *Isaac Newton* (First edition [6], repeatedly reprinted; see Ref. [13]).

1943: Article "Galileo in the history of optics" [4].

1945: "Essay on the development of physics at the USSR Academy of Sciences for 220 years" [14].

After 1945: The chair of the Commission on the History of Physical and Mathematical Sciences at the Division of Physics and Mathematics (after the death of A N Krylov).

After 1945: A member of the Scientific Council of the Institute of the History of Natural Science (IHNS), the USSR Academy of Sciences, a member of the editorial boards of the *IHNS Proceedings* and the *Scientific Legacy* Series issued at the IHNS.

1946: Report "Physics of Lucretius" [15] (in *General Assembly of the USSR Academy of Sciences, 15–19 January 1946*).

1946: Translation of Newton's *Lectures on Optics* from Latin.

1946: Report "I Newton's atomism" in England (presented by H Dale) (see Ref. [16]).

1948: Article "Petr Nikolaevich Lebedev" [17] published in the book *People of the Russian Science* and other articles.

1949, January: Address at the session of the USSR Academy of Sciences devoted to the history of the Russian science.

1949: Article "Lenin and philosophical problems of modern physics" issued in *Usp. Fiz. Nauk* [18].

The works of S I Vavilov on the history of physics and his role in the development of the native science are also characterized in biographical book [19] by L V Levshin, essays [20] by T P Kravets, collection of papers [21], and works [2, 22]. The complete list of S I Vavilov's works on the history of science is presented in *IHNS Proceedings* [23].

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