Operationalism as the Philosophy of L.I. Mandelstam and his School

A.A. Pechenkin
Institute for the History of Science and Technology of Russian Academy of Science, Moscow, Russia

Abstract

The article is dedicated to the philosophy of science which was developed by the outstanding Soviet physicist and leader of a powerful scientific community, L.I. Mandelstam. It is shown that this philosophy can be summed up under the heading "operationalism." Its comparison with the paradigmatic operationalism of Percy Bridgman is undertaken and its German positivist roots are indicated.

1. Preliminaries

In 1949 the fifth volume of the *Complete Works* of the outstanding Soviet physicist Leonid Isaakovich Mandelstam, an Academician and winner of the Lenin and Stalin Prize who died in 1944, had being prepared for publication. The end of the forties and the beginning of the fifties were the years of intensified struggle for the purity of Marxist foundations of Soviet ideology. As part of this struggle the prepared gallery proofs of the volume were singled out for attention. In 1949 a special meeting of the Scientific Council of the Lebedev Physics Institute of the Academy of Sciences rejected the prepared text since it "contained ideological mistakes". The decision was made to replace the editor. Instead of Mandelstam's disciple Sergei Mikhailovich Rytov, another Mandelstam disciple with more authority in the Soviet science hierarchy was appointed, Academician Mikhail Alexandrovich Leontovich, and he was to supply the text with comments intended to correct the "ideological mistakes". In keeping with this decision the fifth volume of Mandelstam's *Complete Works* was published in 1950. The foreword to this volume was written by the official leader of Soviet physics, Academician and President of the Soviet Academy of Sciences Sergei Ivanovich Vavilov.

The next event took place in January 1952. The well-known mathematician Academician Anatolii Danilovich Alexandrov delivered a lecture at the "United Institute Colloquium" of the Lebedev Physics Institute of the Academy of Sciences. His lecture was dedicated to criticism of Mandelstam's philosophical statements. The word "operationalism" resounded throughout this lecture. Alexandrov said:

> This is a prescriptive view of the definition of scientific concepts, a view which was developed by the idealists Percy Bridgman and Philip Frank. This trend toward reducing concepts to operations is a trend of subjective idealism, which tends to eliminate objective reality and to reduce everything to immediate data[1].

After this lecture the qualification "operationalism" with respect to Mandelstam's philosophical claims and ideas became widespread in journals and at seminars. It was repeated in many writings on the philosophy of science published in the USSR (including books as good as Nikolai Fedorovich Ovchinnikov's 1957 book *The concepts of mass and energy in their historical development* [Ovchinnikov, 1957]).

The present article does not aim to describe in full the Soviet philosophical debates which took place at the end of forties and the beginning of fifties. It is not about the development of criticism of Mandelstam's operationalism in the Soviet Union and the history of attacks against operationalism in general. Mandelstam' s operationalism is treated as a phenomenon in the history of ideas, as a conception of philosophy of science worthy of attention in its own right. Mandelstam's operationalism is considered to be a remarkable example of Soviet positivist philosophy of science. This philosophy was not Mandelstam's "personal knowledge". It permeated Mandelstam's famous lectures on a variety of physical theories and disciplines, which constituted the 4th and 5th volumes of his *Complete Works*. Since Mandelstam was the leader of a powerful scientific community in Soviet physics, it is not surprising that his operationalism spread among a wide circle of scientists and found followers.

Section 2 aims to explain who Mandelstam was for Soviet science. Section 3 provides a brief outline of Mandelstam's biography, with special emphasis on the Strasbourg period of his life. In section 4 we cite the most comprehensive and clear of Mandelstam's formulations of operationalism as they are provided in his lectures on the theory of relativity and quantum mechanics. In section 5 we give some examples of how Mandelstam's operationalism worked when he analyzed the foundations of classical physics that was the main field of his contributions (radio-physics, optics and the theory of oscillations). In section 6 the comparison of Mandelstam's operationalism with the paradigmatic operationalism of the American physicist Percy Bridgman is undertaken. In section 7 an attempt to trace back Mandelstam's operationalism to the positivist currents in German science is undertaken.

2. Who was L.I.Mandelstam for Soviet science?

L.I.Mandelstam made contributions to radio-physics, optics, and statistical physics[2]. His contribution to optics reached the Nobel Prize level: in collaboration with G.S.Landsberg he discovered an essentially new effect in crystals, the combinational scattering of light. At the same time a similar effect was discovered in liquids by the Indian physicists Chandraskhara V.Raman and Kariamanikkam S.Krishnan. Raman were awarded the Nobel Prize (1930)[3].

Although Mandelstam did not belong to the pioneers of the theory of relativity and quantum mechanics, he did much to ensure that the Soviet scientific community would adopt the non-classic theories, and his article with I.E.Tamm on the energy-time uncertainty relation is among the classics of the interpretation of quantum mechanics [Mandelstam, Tamm, 1945a,b] (reprinted in [Mandelstam, 1949, pp.306-315])[4] .

Mandelstam had never accepted any considerable administrative position. However during his Moscow years (after 1925) he had become a very influential figure in the Soviet physics. As a professor at Moscow State University he gave lectures and seminars in optics, the theory of oscillations, theory of relativity and quantum mechanics. According to the recollections of his friends and disciples, he was a brilliant university teacher, and his lectures and seminars for students were attended not only by students and young scientists, but also by prominent professors (see: [Rytov (ed.), 1979, 51, 105, 212]). Volumes 4 and 5 Mandelstam's *Complete works* contain his lectures recorded by his students and prepared for publication with the aid of Mandelstam's own notes.

When Mandelstam was a professor at the Odessa Polytechnic Institution (1919-1922) he gained several clever and devoted students. In particular, in Odessa Mandelstam met I.E.Tamm, with whom he collaborated later in Moscow. However the scientific community, which is usually called the Mandelstam school, began to be formed as he accepted the chair of theoretical physics at the Moscow State University and became an acting member of the Institute of Physics and Crystallography at this University. At its core this community consisted of his friends (L.I.Mandelstam's Strasbourg fellow, life-long friend and co-author N.D.Papalexy, above mentioned G.S.Landsberg, with whom Mandelstam collaborated in his optical studies, and I.E.Tamm, with whom Mandelstam collaborated while working on the foundations of quantum mechanics) and graduate students. New graduate students came to this community and usually stayed with it. Mandelstam's school increased by coming graduate students of his former graduate students.

M.A.Leontovich, A.A. Andronov (1901-1952), Alexander Adolfovich Vitt (1902-1938), and S.E.Khaikin (1901-1968) represented the first, oldest generation of Mandelstam's graduate students at the Moscow University. Their contributions to science glorified the Mandelstam school. A.A.Andronov (1946 elected Academician) collaborating with A.A.Vitt developed the theory of non-linear oscillations, the theory in which non-linear science of the second half of the twentieth century was inaugurated. In contrast to the widespread treatment of non-linearity as an approximation, A.A.Andronov elaborated the strict theory of an important non-linear phenomena, the undamped unforced oscillations in dissipative systems called *self-oscillations* (in Russian *avtokolebaniia*, in German *selbsterregte Schwingungen*)[5].

In this article there is no room to describe the achievements of other representatives of Mandelstam's school. It is worth mentioning that even now a number of prominent Russian physicists regards themselves as representatives of the third and fourth generation of Mandelstam's school.

Mandelstam's school would not have been in operation until now if it were not for its high moral prestige. Scientists in the Soviet Union of the 1920s-1930s were trying to be accepted by the new hostile political and ideological environment. They were tempted to get involved in some political enterprises or to include Marxist-Leninist rhetoric in scientific debates. Mandelstam escaped from such temptations, his close friends and disciples escaped or almost escaped from them, too. Moreover, some members of Mandelstam's community of physicists risked their social positions by resisting the general line in Soviet scientific policy.

3. Biographical Notes

L.I.Mandelstam (1879-1944) was descended from a well-to-do Jewish intellectual family. He was educated at Gymnasium in Odessa where his family moved from Mogilev and entered the Physico-Mathematical Faculty of the Odessa Novorosiysk University in 1897. Mandelstam came to Strasbourg to go on with his education. As Mandelstam wrote in his CV:

> I left the Novorosiysk University after four terms study and came to Strasbourg in 1900. There I entered the Physico-Mathematical Faculty where I learned especially physics under Professor F.Braun. In 1902 I obtained the degree of Doctor philos. naturalia on the basis of the my dissertation and examination. In the same year I worked on wireless telegraphy as a private assistant to Professor Braun in Strasbourg and Berlin. In succeeding years I was second and then first assistant at the Institute of Physics of Strasbourg University and led student practical exercises in physics and the research work of graduates. In 1907 I started to give lectures in physics as Privatdozent while holding the position of assistant at the Institute of Physics. In 1913 I became extraordinary Professor with the faculty's charge to give the course of lectures on applied physics. During 1907-1914 I had delivered the following courses: electromagnetic oscillations, wireless telegraphy, the introduction to electrical engineering, the theory of telegraphy and telephony, resonance in physics, the theory of dispersion and other electromagnetic optical phenomena, the kinetic theory of gases. In July 1914 I returned to Russia [6].

Mandelstam and his friend Papalexy left Strasbourg for Russia in 1914 experiencing the danger of war and unemployment.

In the turbulent years of World War I and the Civil War Mandelstam changed jobs and positions several times. For his further career the Odessa Polytechnic Institute was most important, as mentioned above. Mandelstam accepted the chair of physics there in 1918 and a group of young researchers was formed around him.

Between 1922 and 1925 Mandelstam was scientific consultant to the Central Radio Laboratory in Moscow and later in Leningrad, where this laboratory had moved. In 1925 Mandelstam came back to Moscow when he accepted the positions of professor of theoretical physics at the Physical Faculty of Moscow State University and became an acting member of the Institute of Physics and Crystallography of the Moscow University. In 1931 he accepted the chair of oscillations while the chair of theoretical physics was taken by I.E.Tamm.

It should be noted that as recently as 1922 and 1924 Mandelstam was not satisfied with his position and toyed seriously with the idea of leaving the Soviet Union for Germany if any firm were to employ him as a researcher. This is indicated in his letters of 18.06.1922 and 10.03.1924 to R. von Mises, with whom Mandelstam became acquainted in Strasbourg and with whom he since had remained in contact ever[7]. However the letter of 19.06.1926 shows that things had taken a better direction for Mandelstam in the Soviet Union.

Mandelstam took an active part in the organization of the Physics Institute of the Soviet Academy of Science, an institute of the Soviet "big science", with his friends and co-authors N.D.Papalexy and G.S.Landsberg becoming heads of the two leading laboratories of the Institute. By the end of the 1930s Mandelstam's school was centered around this Institute. In 1929 Mandelstam was elected Academician (the highest scientific degree in the Soviet Union and Russia). He was awarded the Lenin Prize (1931) and the Stalin Prize (1942) and decorated with the highest Soviet honors and medals.

Strangely enough, the Strasbourg period accompanied Mandelstam after his death. The events which were mentioned in my preliminary remarks followed an earlier precedent. When in 1947 the campaign against "cosmopolitanism" and "servility to the West" was launched in Soviet physics, the Strasbourg period in Mandelstam's life was recalled (see: [Sonin, 1994, pp.128, 134-135]). Thus, the Dean of the Physics Faculty of Moscow State University, Professor V.P.Kessenikh, accused Mandelstam and Papalexy of having flaunted their privileges in Strasbourg pubs and Professor N.I.Akulov arrived at the accusation that Mandelstam and Papalexy were spying for Germany. Although those statements were not taken seriously by the physics community, they prepared the way for the later “accusation” that Mandelstam was operationalist.

4. How did Mandelstam formulate his operationism?

Mandelstam's operationalism is scattered among the notes of his lectures and seminars, which constitute the fourth and fifth volumes of his *Complete Works*. The most comprehensive and clear of the formulations can be found in his 1933-1934 *Lectures on the Theory of Relativity* and 1939 *Lectures on Quantum Mechanics.* Mandelstam formulated the principles of his operationalism in his discussion of the nature of physical concepts and the structure of physical theories.

The nature of physical concepts.

In *Lectures on the theory of relativity*, where he tended to follow directly Albert Einstein [Mandelstam, 1950a, 90-305], Mandelstam spoke mainly about the nature of concepts. He was clearly aware of the philosophical character of the problem which he posed, although he never used the word “philosophy”. Having outlined the problem of reconciling Galilean relativity in classical physics with the principle of the constant velocity of light, the problem which Mandelstam took to be Einstein’s point of departure, Mandelstam stated [Mandelstam, 1950a, p.177-178] :

> In order to do this, another discussion should be launched, the discussion of the structure of physical concepts. I can not speak about it in details, for 1) I am not a specialist in this field and do not know these matters enough and 2) these matters would take us far away from our problems. However, some important peculiarities, without which a physicist can not work, we shall see. We shall see that we speak a lot of words which have no content, and confusions result from this. Let us look at some simple facts.
>
> When we are speaking about some scientific laws, for example, Newton’s laws, we mean formulas containing x, y, z. To test these formulas we need to substitute certain numbers for x,y,z. However to do so, we must be able to measure length.
>
> What does it mean to measure length for a physicist? At first he must have a unit of length. What is the unit? This is a distance between two marks on the rod which is kept in Paris...

This is not all. Once a physicist has a unit he also needs a technique for measuring. He needs a real process that gives him a number which is, by definition, the length of the object. A physicist must have a prescription for how to measure length.

Mandelstam emphasized Einstein's philosophical contribution to physics. He said [Mandelstam, 1950a, p.180, 196]:

A number of concepts is not experienced but accepted by definition in the course of cognition of the real world. Einstein shows that it is the point that has been overlooked and this is his great contribution to science... Einstein performed his great service when he elucidated that the concept of simultaneity is a concept like the concepts of length and the time of an event.

Discussing the physical concepts in his *Lectures on quantum mechanics* [Mandelstam, 1950a, pp. 347-415] Mandelstam seemed to follow Heisenberg's celebrated 1927 paper in which the uncertainty relations were formulated, though he never referred explicitly to this article. In methodological terms, Heisenberg in turn apparently followed Einstein's 1905 article[8].

Mandelstam said [Mandelstam, 1950a, p.354]:

Quantum mechanics rightly abandons prejudice that laws of macro-world are valid in micro-world. But only the mathematical part of the theory completely proceeds from this point of view. In the text-books it does not taken sufficiently into account that prescriptions for the transaction [from the mathematical technique to the real objects] must differ from those in classics.

If in classics I speak that x is the position of a material point than I mean a clear prescription: if I set properly a rigid rod graduated according to a definite prescription, than x numbers that marking with which the point coincides.

As far as we speak about the molecular issues this prescription is not performable…Thus having called *x* the position I only pretend that I establish the relation of it to the nature. With such a definition theory is in the air.

Mandelstam continued [Mandelstam, 1950, p.358]:

The uncertainty relations trouble us, since calling *x* and *p* position and momentum respectively we are thinking about the corresponding classical magnitudes... Why do we called *p* momentum? This is self-delusion again... Until we have no new measuring prescriptions it would be better not to use old terms.

He explained the uncertainty relations as follows:

The very definition of quantities, with which the theory works, presupposes the theoretical impossibility of simultaneous exact values of x and p. The situation is the same as in classics. The question "What is the oscillation frequency of a pendulum at a particular instant of time ?" is absurd. So, the thing is in the very definition of the concept.

Mandelstam gave the usual operational (for Mandelstam, "prescriptive") definitions of the position and the momentum of a particle: the position of the dot on a photographic plate resulting from the incidence of a particle on the plate, and the curvature of the track of a particle in a cloud chamber, respectively. However, he pointed out the inadequacy of such an approach: the momentum of an uncharged particle (say, a neutron) can not be measured by measuring the curvature of the track of the particle in a cloud chamber. Mandelstam stressed that direct measurements are exceptional and outlined the theory of indirect measurement, which was not articulated by Heisenberg and the other founders of quantum mechanics. This was an important move.

In his essay in the Mandelstam memorial volume (reprinted in [Tamm, 1991, p.275]) I.E.Tamm commented on this move as follows:

As far as I know, Leonid Isaakovich was the first to include in lectures the very important distinction between direct and indirect measurements in quantum systems. The last stage in any measurement of a quantum system necessarily has a macroscopic character. L.I. calls measurement direct when the first measurement step is macroscopic. Example: An electron incident on a photographic film leaves a blackened spot. The macroscopic coordinate of the spot, by definition, is the coordinate of the electron upon its impact on the film. It is important to note that the direct measurements are possible only for free or nearly free particles in free fields. For example, it is impossible to determine the coordinate of an electron in a hydrogen atom by placing a photographic film inside the atom.

In addition to direct measurements, indirect ones are also possible. In these we force the quantum system on which we want to make measurements to interact with another micro-system on which direct measurements are possible. The date of these direct measurements we use for theoretical calculations of the values of the quantities relevant to the first system. Example: By measuring the angular distribution of electrons scattered by an atom, we can find the distribution of bound electrons in this atom.

Thus Mandelstam extended the concept of operational definition by including "indirect operational definition" suggesting theoretical calculations. With this extended operationalism he examined the foundations of quantum mechanics.

The structure of physical theories.

Mandelstam gave no explicit indication of the philosophical tradition within which he treated the structure of physical theory. However, it was clear that he developed his discussion of a physical theory along the same lines as positivistically-inclined contemporaries like Rudolf Carnap and Henry Margenau and in keeping with the influential positions subsequently articulated by Karl Hempel and Ernest Nagel. One can read in Mandelstam's *Lectures on Quantum Mechanics*:

Every physical theory consists of two parts that supply each other. I shall start by indicating what the second part is. This is a set of equations of a theory (Maxwell's equations, Newton's equations, Schroedinger's equation, etc.). Certain symbols are contained in these equations (x, y, z, vectors E and H, etc.). With this the second part is completed.

The first part of a physical theory consists of the connections of these symbols (quantities) with the physical objects, connections, which proceed in accordance with the specific prescriptions (we must have the real objects as standards and a real measurement technique) [Mandelstam, 1950a, p.349].

The building of a physical theory can be divided into two stages...

First of all, one should introduce physical quantities that depend on the field to which this theory refers. Among them we assume mathematical relations (for example, in the form of differential equations).

The second stage consists of connecting the mathematical quantities with the physical objects. To achieve this, for every quantity we must formulate a definite prescription for how to attach a numerical value to this quantity [Mandelstam, 1950a, p.408].

Having reviewed the mathematical scheme of quantum mechanics (self-adjoint operators, the wave function, the Shroedinger equation), Mandelstam said [Mandelstam, 1950a, p.359]:

We need to coordinate the symbols, belonging to the Shroedinger equation, with the objects of nature. For a physicist to state such a relation means to give an actual prescription according to which numerical values of physical quantities could be extracted from the real objects.

Mandelstam's positivist inclinations are thus apparent, but it should be emphasized that he did not distance himself from authentetic operationalism in quite the same fashion as Margenau, Hempel, and Nagel. They treated the operational definition as a particular case of "correspondence rules" (a conventional term for sentences which functionally attach empirical meaning to theoretical terms and garantee the cognitive significance of the theory). What was Mandelstam's position here? We shall reach a more comprehensive formulation of Mandelstam's operationalism by comparising it with Bridgman's paradigmatic operationalism in the sixth section. Before doing so we must continue our journey toward Mandelstam's own formulations. In the next section we shall consider how Mandelstam, proceeding from the operationalist point of view, treated several fundamental concepts of classical physics, concepts with which he was in touch within the main portion of his research and teaching.

5. Operationalism in classical physics: two examples

We shall consider two examples of how Mandelstam trated the conceptual problems of classical physics in operationalist fashion. These examples borrow from his 1930-1932 *Lectures on Oscillations* (4th volume) and from his 1932-1933 *Lectures on Selected Issues in Optics* (5th volume). Mandelstam also dealt with these same issues in his lecture delivered at the 1931 All-Union (National) conference on oscillations [Mandelstam, 1950, pp.52-86].

Both examples are concerned with the reality of components resulting from the Fourier analysis of physical phenomena. Mandelstam summarized his view of problems which arose in connection with the Fourier expansion by stating the following: "Every expansion is correct and reasonable in relation to the experimental device which is in use" [Mandelstam, 1955, p. 173] and "The question of the reality of the expansion into a sinusoidal series often arises. This question attains meaning once it is tied to the apparatus that registers oscillations" [Mandelstam, 1950a, p.119].

As one of Mandelstam's former students recalled, at one of the seminars Mandelstam explained his approach to physical reality as follows. Say we have a collection of balls, which are either big or small, and at the same time either ferrous or cupric. If we are sorting the balls with a sieve, the collection consists of big and small balls. If we are sorting them by magnet the collection consists of ferrous and cupric balls [9] .

The examples, which we planning to discuss in this section differ from each other with regard to the physical contexts in which the problem of the reality of the Fourier components arises. The *first* example is borrowed from radio-physics.

In 1930 paper in *Nature* the outstanding English radio-engineer Ambrose Fleming struggled with the "widely diffused belief in a certain theory of wireless telephonic transmission that for securing good effects it was necessary to restrict or include operations within certain width of “wave band” [Fleming, 1930, p.92].

According to Fleming, "a “wave band” was merely a kind of mathematical fiction and did not correspond to any reality in Nature" [Fleming, 1930, p.92].

Fleming meant the "wave band theory" which was implied by the series expansion of the modulated signal emitted by the transmitter. "When we sign or speak to affect the microphone at a broadcasting studio", Fleming wrote, "the result is to cause the emitted vibrations, which are called the carrier waves, to fluctuate in amplitude but does not alter the number of waves sent out per sec". Suppose the broadcasting station emits a carrier wave of frequency p. If q is the acoustic frequency, then the modulated vibration can be expressed by the function

$$a = A \cos qt \sin pt. \qquad (1)$$

However this function can be expanded as follows:

$$a = A/2 \{\sin (p+q)t + \cos (p-q)t\}. \qquad (2)$$

In Fleming's opinion, the modulated signal (1) corresponds to something in Reality, whereas the "wave bands" presented in (2) are merely a kind of mathematical fiction. With this paper on the "wave band" theory Fleming launched a polemical debate in the pages of *Nature*.

Oliver Lodge, the prominent English physicist, contributed to the polemics [Lodge, 1930]. He greeted Fleming’s "admirably clear article" as an opportunity to raise the question whether alternative mathematical formulations must invariably correspond to some physical reality. In contrast to Fleming, Lodge argued that the "wave bands" existed, based on his understanding of the physical properties of the electromagnetic field.

Mandelstam had first encountered Fleming's theoretical points of departue during his Strasbourg years. In articles from 1906-1907 he had critisized Fleming's calculations of the radiation emitted by the inclined antenna invented by Marcony and Fleming ([Mandelstam, 1908];a Russian translation is printed in [Mandelstam, 1948, pp.154-161]).

In reacting to the "wave band" discussion Mandelstam did not mention O.Lodge's contribution to it. As far as Fleming's position was concerned, Mandelstam's aim was to disavow it.

According to Mandelstam, any question about the reality of an object should be posed with respect to an apparatus or instrument by means of which the object in question is assigned a given physical value. "The question whether "wave bands" possess reality makes no sense. This is not the way to pose the question. A transition from formula 1 to formula 2 is mere trigonometry. No reception apparatus can detect whether there is one modulated wave or three nonmodulated waves from three transmitters (Mandelstam's formulas differed slightly from Fleming's - A.P.). The question of the reality of wave bands is the same sort of question as, for example, what is real, the fact that 10=2+8 or that 10=5+5?" [Mandelstam, 1955, p.177].

If we are interested in applying a more selective receiver, representation (1) is not helpful. Such a receiver would attribute reality only to that component of equation (2) to which it is tuned. However, a normal receiver (i.e., not very selective) gives physical reality to a single modulated wave.

Mandelstam also expressed this as follows: Let a tuning fork emit sound which is periodically (with the period $2\pi/p$) interrupted by a hand which rises between the tuning fork and a receiver. If we use another tuning fork as the receiver it distinguishes between the components of the sum (2). But a human ear hears only the single modulated signal (1).

The *second example* touches on a more complicated problem [Mandelstam, 1950a, pp.66-74]. In 1932 in his “Lectures on Selected Issues in Optics” Mandelstam discussed a paradox which arose in physical applications of the Fourier integral. This paradox was physical rather than mathematical, and it is connected to the same principles of resonance theory as the reality of the "wave bands". However, here the problem was more complicated, for it involves a continuous spectrum.

Let f(t) represent a wave packet, where

$$f(t) = \sin nt , \qquad - T/2< t < + T/$$
$$f(t) = 0 , \qquad t > T/2.$$

We also let $nT = 2\pi N$, where N is an iteger. Thereby we provide for the continuity of the function f(t) at $t = +/- T/2$.

The expansion of f(t) into the Fourier integral is

$$f (t) = 1/ \sqrt{2 \pi} \int_{-\infty}^{+\infty} g(u)\, e^{iut}\, du.$$

Having calculated the Fourier factor we arrive at

$$f(t) = n/ \pi \int_{-\infty}^{+\infty} \frac{\sin (u-n) T/2}{u^2 - n^2}\, e^{iut}\, du \quad . \qquad (3)$$

The last formulae is a superposition of infinite sine waves which extends from $t= -\infty$ to $t =+\infty$. The paradox is formulated as follows: Before $t =- T/2$ function f(t) is equal to zero. How is it that an “infinite sum” of non-zero sine waves turns out to be equal to zero?

If the sine waves were real, we would see the light before it was switched on. Naturally enough, one says that these individual sinusoidal waves, in contrast to their sum, are not real. However, this answer presupposes a non-operationalist — and according to Mandelstam, non-physical — notion of reality.

Mandelstam proposed another solution. Taking into account the equivalence between the left- and righthand sides of equation (3), one can only conclude that the actions of the infinite sine waves that constitute the expansion of f(t) may be summed in such a way that the result of their summation is zero. “We shall prove”, Mandelstam said, “that this is the case even for a resonator with arbitrary small damping” [Mandelstam, 1950, p.69].

Mandelstam proved that even a highly selective receiver distinguishes a continuous band of infinite sine waves rather than a single sine wave, and what is more, summation of the sine waves within this band yields zero for $t < -T/2$.

Sine waves are nevertheless real in some physical sense. To see this reality we need to turn again to the interaction of the signal f(t) with a resonator and then consider, say, the spectrum of $\int|y(t)|^2dt$, where y(t) describes the oscillations of the resonator. Following Mandelstam let us examine two limiting cases: 1) if $nT >> \omega_0/\delta$ and 2) if $nT << \omega_0/\delta$, where ω_0 is the proper (eigen) ferquency of a resonator, δ is the constant of its damping.

In the former case, with high damping, the resonator shows a spectrum whose shape does not depend on the duration of the wave train represented by the lefthand side of the equation, as if the signal acting on the resonator were an infinite sine wave. In the latter case, with low damping, the shape of the spectrum of $\int|y(t)|^2dt$ depends on that of the train represented by f(t).

Reading through notes of Mandelstam's lectures and seminars, we find several treatments of reality the Fourier components related to other physical problems — “anomalous dispersion and the principle of relativity”, “light beats”. From a methodological point of view, however, we may dispense with these, since Mandelstam's comments on these problems add nothing essential to the discussion above.

Thus, according to Mandelstam, the physical reality of a quantity is not absolute. The same quantity can be real with respect to one experimental operation and not real with respect to another experimental operation. Mandelstam emphasized that from the point of view of physics, a quantity is real (and hence meaningful) if it is applied in the description of an experimental setup which in turn assures its measurability, or at least its recognizabilty.

6. The main points of the comparison with P.Bridgman's operationalism

We are now in better position to compare Mandelstam's operationalism with the philosophy of science of the American physicist Percy William Bridgman, whose views were widely discussed and on occasion severely criticized. The “operationalism” most famously associated with Bridgman bears close comparison with Mandelstam’s own philosophical conceptions, as our application of the term throughout this article would suggest.

Mandelstam had much in common with Percy Bridgman. Both came to the philosophy of science as working physicists. In developing their philosophical views, both were guided by the methodology implicit in Einstein‘s 1905 article on special relativity. Each of them emphasized the importance of experiment and measurement for the clarification of physical concepts, and both saw in their philosophical accounts a tool for criticism rather than a "doctrine". They attacked "pseudo problems" and struggled against "language stereotypes" (we deliberately use a term which neither Bridgman nor Mandelstam used and which is thus neutral with respect to them). Finally, Bridgman and Mandelstam alike explained their philosophical accounts using the same examples of "length", "time", and " simultaneity".

We will concentrate here on the differences between Bridgman's and Mandelstam's approaches, however. These differences may be summarized in the following four points:

1. In contrast to Bridgman’s "essentially American philosophy", as Gerald Holton has put it [Holton, 1986, p.132], Mandelstam emphasized the inter-subjective character of his operationalism: according to him the operations which supply scientific terms with meaning must be repeatable and reproducible. In his *Lectures on the Theory of Relativity* he pointedly emphasized that operations

should meet the requirements of "invariability and unambiguity" [Mandelstam, 1950a, p.182]. Of course, Bridgman also referred to his operations as physical and hence reproducible for his scientific colleagues. "In principle the operations... should be uniquely specfied," wrote Bridgman [Bridgman, 1927, p.10]. But his operationalism gradually revealed a solipsist tenor which become stronger in his later writings. As early as 1936, his *Nature of Physical Theory* demonstrated that he regarded operations as "private", as "mine and naught else" [Bridgman, 1936, p.14].

2. Originally Bridgman restricted his "operational analysis" to physical operations which could actually be performed. In this manner he ensured knowledge against the contradictions introduced by "mental operations". In his later writings he extended his operationalism by including "paper and pencil" operations, that is, theoretical calculations [Bridgman, 1938, pp. 123; 1950]. Mandelstam had never formulated his operationalism in so rigid form as Bridgman's original conjunction of the two precepts, "the concept is synonymous with the corresponding set of operations" and " if the concept is physical..., the operations are actual physical operations" [Bridgman, 1927, p. 5]. In his *Lectures on Quantum Mechanics* Mandelstam formulated his notion of operations by including theoretical calculations as an essential part of any operations, as we saw above in his theory of indirect measurements. In contrast to Bridgman's vague "paper and pencil operations", Mandelstam's indirect measurements were subject to the definite rules presupposed by quantum mechanics.

3. According to Bridgman, each different experimental procedure defines a distinct concept. So there are as many distinct concepts of, say, length as there are procedures for determining it. Once a scientist employs a single conceptual term for all these procedures, he is engaged in illegitimate equivocation.

By contrast, Mandelstam admitted different operational ("prescriptive") definitions for the same concept. Moreover, if (at least) two operational definitions can be formulated for a physical concept, then one of them may be treated as an empirical sentence testable against observation and experiment, with the other regarded as a formal definition.

This is very much in keeping with the stile of the philosophers like Carnap, Margenau, and Hempel. Mandelstam's operational definitions provided only a partial interpretation of the theoretical terms specfied in the mathematical framework of the theory. Moreover, if an operational definition was indirect (given by an indirect measurement), it directly referred to theoretical principles.

4. Bridgman did not devote much room to "physical reality" in his writings. He adopted a strongly critical stance toward the issue, aiming his "operational criticism" at this philosophical concept in hopes of limiting its applicability. Mandelstam, by contrast, was concerned with the concept of physical reality when he analyzed quantities of classical physics (see, the preceding section). In essence he formulated an operationalist criterion for physical reality.

This criterion does not, however, exhaust Mandelstam's concept of physical reality. In contrast to Bridgman, Mandelstam constantly reiterated that "operations" and "prescriptions" relate the mathematical symbols to "nature", to "real objects", and to "reality," rather than to "experience", "observations", or "sense data". Furthermore, when he wrote and spoke about the confirmation of theories, he applied the qualifications "true" and "false" to theories.

True, Mandelstam's was a week version of realism. Mandelstam rejected "a priori concepts" which were given "by themselves" (see: [Mandelstam, 1950a, p. 183, 406]). Throughout his lectures the image of nature remained opened to discussion. We may assert that reality exists, but we may not say once and for all which object is real. Nevertheless Mandelstam retained some ontological parameters. He was occasionally inclined to accept "ontological determinism".

Let us turn again to Mandelstam's *Lectures on Quantum Mechanics*. Mandelstam adhered to von Neumann's discussion of the completeness of quantum theory. This does not mean that Mandelstam shared von Neumann's philosophy of causality. He tended to avoid the indeterminism which von

Neumann proclaimed. Thus von Neumann wrote that "es gibt gegenwaertig keinen Anlass und keine Entschuldigung dafuer, von der Kausalitaet in der Natur zu reden" [Neumann, 1932, p.167]. Mandelstam said, however, the following [Mandelstam, 1950a, pp.403, 414]:

They say that von Neumann demonstrated that the construction of the theory on the basis of determinism is impossible. I think that such phrases say next to nothing.

If they sometimes say that von Neumann demonstrated that the causal theory of the atom phenomena is impossible then this is not the case.

This was not identical with von Neumann's above claim.

To conclude let us turn once more to Bridgman's operationalism. Although Mandelstam's philosophy of science may be summarized within the rubric designated by Bridgman's “operationlism”, it does not lack originality. With this we arrive at the question of the origins of Mandelstam’s philosopy.

7. What philosophical tradition lay behind Mandelstam’ s operationalism?

Was Mandelstam influenced by Bridgman’s celebrated *The Logic of Modern Physics*? The materials at our disposal offer no grounds for answering in the affirmative. It is likely that Mandelstam arrived at his operationalism independently by studying Einstein’s and Heisenberg’s articles and meditating on the foundations of physics.

This conclusion regarding Bridgman’s influence may be supported by the following observation. As mentioned above, Mandelstam met R.von Mises in his Strasbourg years and went on to communicate with him when they were isolated from each other by war in Europe and revolution on Russian soil.

Papalexy recolls Mandelstam and von Mises as frequently engaged in discussion of the philosophical foundations of physics [Mandelstam, 1948, p.20]:

Leonid Isaakovich spoke often with Mises, an excellent mathematician, who also enjoyed strict logical constructions and sophisticated logical demarcations. Discussions with Mises, who was a leader in statistical mechanics and the theory of probability, satisfied Mandelstam's demands for complete and clear thought. Together with H.Poincare's brilliant ideas presented in his *La Science et l'Hypothese*, those discussions helped Mandelstam here in Moscow to elaborate complete and consistent foundations of statistical physics.

Mandelstam and von Mises exchanged letters in the 1920s and 1930s (the last letter of Mandelstam to R.von Mises in von Mises’ collection of the Harvard University Archives was dated 15.03.1937). Mandelstam visited von Mises when he was in Germany in 1923 and he stayed at the von Mises’ when he visiting Germany in 1930. It is very probable that they continued their discussion on the philosophy of physics when they met together. Mandelstam wrote to von Mises in his letter of 09.02.1928[10].

IIn der letzten Zeit interessiere ich mich sehr fuer die Wellenmechanik. Wie gern wuerde ich mit ihnen ueber verschiedene Fragen sprechen.

Mandelstam wrote to von Mises in his letter of 15.03.1937:

Wan erscheint Ihr *Kleines Lehrbuch des Positivismus*? Ich bin sehr gespannt darauf.

Mandelstam and his desciples enthusiastically greeted the appearance in 1928 of *Wahrscheinlichkeit, Statistik, und Wahrheit* (J.Springer, 1928), in which von Mises proposed an essentially operationalist definition of probability within Machian philosophical framework[11]. Mandelstam contributed to the rapid publication of the Russian translation [Mises, 1930], and he and his proteges initiated discussion of the book in Soviet seminars[12] and journals[13]. Mandelstam wrote to von Mises in his letter of 9.02.1928:

Ich will Ihnen ein Paar Worte ueber die Uebersetzung Ihres neuen Buches sagen.. Ich habe darueber mit Prof. Kagan, der der wissenschaftlichen Abteilung des Staatsverlags vorsteht, gesprochen. Er hat sehr viel Interesse fuer das Buch und will Ihnen darueber schreiben, oder hat es vielleicht schon getan.. . Ich fuer meine Person bin furchtbar gespannt auf Ihr Buch und halte es fuer ausserordentlich wuenschenswert, dass es ins Russische uebersetzt wird.

Von Mises was among the great advocates of neopositivism and a major proponent of Mach's philosophy. It is curious that although German positivists took note of Bridgman's *The Logic of Modern Physics,* von Mises did not mention the American's operationalism in his 1939 *Kleines Lehrbuch des Positivismus* or in previous philosophical writings. He mentioned it only in the 1951 English version entitled *Positivism*. "The physicist P.W.Bridgman", von Mises wrote, "devised in his operationalism a theory of knowledge that is closely related to, and in full agreement with, the main teachings of Mach" [Mises, 1951, p.361].

As was mentioned above, von Mises in essence developed the operationalist definition of probability in his book *Wahrscheinlichkeit, Statistik, und Wahrheit*. It should be noted that he did not use the term "operationalist definition" then and, in contrast to Bridgmans', his definition was connected with theoretical principles and included theoretical considerations.

In attempting to answer the question about the generic relation of Mandelstam to Bridgman we find ourselves in the same difficult position in which Max Jammer found himself when discussing the evidence for operationalism in Heisenberg's original 1927 article formulating the uncertainty relations. On the one hand, Heisenberg's article shows apparent operationalism. On the other hand, "it would be rash to classify Heisenberg as a pure operationalist" [Jammer, 1974, p.58]. To justify this Jammer referred to the fact that P.Bridgman did not approve of Heisenberg's interpretation of the uncertainty relations, while Heisenberg in turn did not accept Bridgman's 1929 explanation of these relations [Jammer, 1974, p.472].

Thus, as in Madelstam's case, there is no indication that Hieisenberg's operationalist interpretation of his uncertainty relations and Bridgman's operationalism were genetically connected. Heisenberg developed in his 1927 paper his own version of operationalism, which can be traced back to the kinematical part of Einstein's 1905 article and to E.Mach's positivism.

Mandelstam's education at Strasbourg University and his subsequent scientific contacts prepared him for working out operationalist philosophy of science. He was familiar with German positivist literature, and aside from his contacts with von Mises, one can also refer to Mandelstam's *Borovoie diary*[15], in which he cites L.Witgenstein, for example:

Zu einer Antwort, die man nicht aussprechen kann , kann man auch die Frage nicht aussprechen.

Mandelstam's teacher and mentor Ferdinand Braun was among a number of scientists who nominated E.Mach for the Nobel Prize between 1910 and 1914. Braun's letter of nomination indicated that since the Nobel prize might soon be awarded for the new theory of space and time, it should first go to E.Mach as an early advocate of these ideas, and also as a major experimentalist. He also insisted on Mach's wider influence via his "philosophical clarifications" and "his clear, profound historical-physical studies"[14]. F.Braun wrote in his letter that Mach gave a "strict idea how our fundamental physical concepts were being formed" and, "from the point of view of the theory of cognition, answered the question what our definitions of physical concepts meant".

Braun himself was no typical Machist, and he did not go so far in his philosophical statements. Nevertheless he was close to Machism when he treated the law of conservation of energy as a regularity rather than a normative principle , in contrast to some of his contemporaries, who were inclined to regard energy as a substance, [Braun,1899, p.19-21]. Without positing the cognition of substance as his goal, Braun thought there remained only the search for a "successful combination of facts".

F.Braun's philosophy of science, which he never presented explicitly, involved elements of operationalism. Thus, Mandelstam could have attended F.Braun's popular lecture *Ueber drahtlose Telegraphie und neuere physikalische Forschungen* delivered in 1905. In this lecture F. Braun stressed that homogeneity and heterogeneity of bodies was not their immanent characteristic but depended on the problem being solved and the corresponding experimental arrangement. In an empiriocritical fashion he interpreted what substance was in the final analysis. One might say that he subjected substance to a kind of operational analysis. Having reviewed in this lecture how physics progressed in studies of the structure of matter, F.Braun expressed his skepticism regarding the existence of such a substance. He concluded his discussion of radium radiation as follows [Braun, 1905, p.21]:

> Wir kennen die Substanz bisher nur in minimalen Mengen, und die Erscheinungen selber, so frappant sie klingen, werden, aus Naehe gesehen, recht unscheinbar.

So, Mandelstam brought to Soviet science the methodology of the German community of physicists. In interaction with the scientific and pedagogical problems which Mandelstam addressing in the Soviet Union, this methodology yielded his operationalist philosophy.

Conclusion

When surveying the current literature, we can observe that there are two approaches to the history of Russian science during the Soviet period.

1. The approach of Sovietology is rather popular. On this view, the specific features of Soviet science as a historical phenomenon are of most importance. Typical topics in this vein are “science and the state”, “science and state ideology”, “Lysenkoism”, etc.

2. However, from the point of view of the genesis of scientific ideas, laboratory life, and the structure of informal scientific communities, physics in the Soviet Union was very close to regular Western physics. In fact, it can be regarded as a part of this physics. The objective of our article is to show that Soviet physics shared with its Western counterparts not only the scientific problems, theories and ailments but also the philosophical backgrounds, that is, philosophical problems, theories and deceases.

I wish to thank Doctor Karl Hall who was kind enough to help me improve my text for publication.

---

[1]Quoted in [Sonin, 1994, p.181].

[2]L.I.Mandelstam's biography is contained in C.Gillispie's Dictionary of Scientific Biography (New York, 1974). The author is Iakov Grigorievich Dorfman.

The most important and famous Mandelstam's biography in Russian was written by his life-long friend and co-author Nikolai Dmitrievich Papalexy (1880-1947) [N.D.Papalexy,1948] (reprinted in: [Rytov (ed.), 1979, 5-26]). This biography had been adjusted by the outline of the late period of Mandelstam's life written by Mandelstam's good friends and co-authors Grigorii Samuilovich Landsberg (1890-1957) and Igor Evgenievich Tamm (1896-1971), and his former graduate students Gabriel Semenovich Gorelik (1906-1957), Michail Alexandrovich Leontovich (1903-1981), and Sergei Michailovich Rytov (1908-1996) [Mandelstam, 1948, 32-66] (reprinted in [Rytov (ed.), 1979, 27-52]).

[3]Immanuil Lazarevich Fabelinsky (b.1911) made an attempt to describe the history of the discovery of the combinational scattering of light (called the Raman effect in the West) and evaluate the contributions made by Mandelstam and Landsberg, on the one hand, and Raman and Krishnan, on the other hand [Fabelinskii, 1978].

[4]I. E. Tamm who regarded himself as a disciple of Mandelstam [Tamm, 1991, 269] became Nobel Prize winner in 1958.

[5]A.A.Andronov, A.A.Vitt, and S.E.Khaikin's book *The Theory of Oscillations* ran into three editions in the Soviet Union ([Andronov, Khaikin, 1937], [Andronov, Vitt, Khaikin, 1965; 1981]. Two English translations of this book were published [Andronov, Chaikin, 1949; Andronov,

Khaikin, Vitt, 1966]. German translation of the second Russian edition was published in 1965 (Akademie-Verlag: Berlin). S.E.Khaikin, the co-author of A.A.Andronov and A.A.Vitt, are also known as the author of the fundamental book *Physical Foundations of Mechanics*.

A.A.Vitt was arrested in 1937 and died in a concentration camp. His name had been eliminated from a title page of the 1937 first edition of Andronov's, Vitt's, Khaikin's book *The Theory of Oscillations*. Vitt's name had been rehabilitated as early as under Stalin's power, and Andronov took the opportunity of writing some warm wards about him in his 1945 article.

[6] *The Archives of Russian Academy of Sciences*. Stock 1622, list 1, item 51.

[7] *The Harvard University Archives*, HUG 4574.5, box 2.

[8] The real history was more complicated. As is well-known, in the 1960s Heisenberg reminiscently recalled how he spoke with Einstein in 1926, who told him the famous phrase that "it is the theory that decides what we can observe". However, these recollections do not contradict the observation that both Einstein's 1905 article in its kinematical part and Heisenberg 1927 uncertainty article were written in the same operationalist tenor. It is not surprising that, as Heisenberg pointed out, he recalled his conversation with Einstein just before writing his uncertainty paper. "Operational definitions of fundamental concepts subject to quantum mechanics and the uncertainty relations quickly followed. The theory did indeed decide what could or could not observed and remembered" [Cassidy, 1989, p.239].

[9] Cited in [Gorelik G.S., 1979, p. 153].

[10] The Harvard University Archives, HUG 4574.5, box 2.

[11] This book was a popular presentation his ideas which were first published in 1919.

[12] The author's interview with S.M. Rytov (July, 1992); the Collection of the Communist Academy (the Archives of the Russian Academy of Sciences. Stock 350, list 2, item 17).

[13] *Pod Znamenem marksizma*, 1928, No.: 7-8; *Estestvoznanie i marksizm*, 1929, No.:1; *Uspekhi Fizicheskikh Nauk*, 1929, vol .9, issue 2, pp.141-166; 1930, vol.10, issue 4, pp.437-462.

[14] The leters to Nobel Committee on behalf of E.Mach from F.Braun and some other prominent physicists are printed in [Blackmore, Hentschel (eds), 1985].

[15] Quoted in [Gorelik G.E, 1995, p.76]. Within 1941 and 1943 Mandelstam was living in the small town Borovoe (Kasahstan) where the elite of the Academicians was evacuated.

Bibliography

Andronov Alexandr A.: “Mandelstam i teoria kolebanii <<L.I.Mandelstam and the Theory of Oscillations>>”. In: [Rytov (ed.),1979].

Andronov Alexander A., Khaikin Semen E.: *Teoria kolebani*i <<Theory of Oscillations>>. ONTI: Moscow; Leningrad 1937.

Andronov A.A., Vitt Alexandr A., Khaikin S.E., *Teoria kolebanii*. Fizmatgiz: Moscow 1965.

Andronov A.A., Vitt A.A., Khaikin S.E.: *Teoria kolebanii.* Nauka: Moscow 1981.

Andronov A.A., Chaikin S.E.: *Theory of Oscillations.* Princeton Univ. Press: Princeton 1949.

Andronov A.A., Khaikin S.E., Vitt A.A.: *Theory of Oscillators.* Pergamon press: Oxford 1969.

Blackmore John T., Hentschel Klaus (eds.): *Ernst Mach als Aussenseiter.* Viena: Wilhelm Braunmueller 1985.

Braun Ferdinand: *Ueber physikalische Forschungsart. S*trassburg 1899.

Braun F.: *Ueber drahtlose Telegraphie und neuere physikalische Forschungen*. Heitz: Strassburg 1905.

Bridgman Percy: *The Logic of Modern Physics.* Macmallin: New York 1927.

Bridgman P.: *The Nature of Physical Theory*. Princeton Univ.Press 1936.

Bridgman P.: “Operational Analysis”, *Philosophy of Science.* Vol. 5, 1938, pp. 114-131.

Bridgman P.: *Reflections of a Physicist.* Phil. Library 1950.

Cassidy David C.: Uncertainty: The Life and Science of Werner Heisenberg. W.H.Freeman: New York 1992.

Fabelinsky Immanuil L.: “Otkrytie kombinatsionnogo rasseiania sveta <<Discovery of the Combinational Light Scattering>>”. *Uspekhi fizicheskikh nauk.* 1978, vol.126, pp.124-152.

Fleming J.A.: “The "Wave Band" Theory of Wireless Transmission”. *Nature.* 1930, vol.125, pp.92-99.

Gorelik Gabrilel Salamonovich: L.I.Mandelstam I uchenie o rezonanse <<L.I.Mandelstam and the conception of resonance>>. In: [Rytov, ed., 1979, p.153].

Gorelick Gennadii Ephimovich: Filosofskie osnovannia atomnogo proekta <<The Philosophical Backgrounds of the Nuclear Project>>, *Priroda*, 1995, No.:7, p.76.

Heisenberg Werner: “Ueber den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik”. *Zeitschrift fuer Physik.* 1927, Bd.43, s.172-198.

Holton Gerald: *The Advancement of Science, and its Burdens*. Cambridge, etc.: Cambridge Univ.Press 1986.

Jammer Max: *The Philosophy of Quantum Mechanics*. Wiley: New York 1974.

Krylov Nikolai Mifodievich, Bogoliubov Nikolai Nikolaievich: Osnovnye problemy nelineinoi mekhaniki << The basic problems of Nonlinear Mechanics>>, *Izvestia Akademii nauk SSSR*. Seria 7. Otdelenie matematicheskikh I estestvennykh nauk. 1933, No.: 4, pp.475-498.

Krylov N.M., Bogolubov N.N.: *Introduction to Nonlinear Mechanics*. Kiev: izd.ANUkr.SSR, 1937.

Krylov N.M., Bogoliubov N.N., *Introduction to Nonlinear mechanics*. Princeton: Princeton University Press. 1947.

Lodge Oliver: The “Wave Band” Theory of Wireless Transmission. *Nature*, 1930, vol.125, No.: 3147, pp.271-272.

Mandelstam Leonid I.: *Polnoe sobranie trudov* <<Complete Works>>, vol.1-5. Izd. AN SSSR: Moscow 1948-1955:

Vol.1, ed. by S.M.Rytov. 1948,

Vol.2, ed. By S.M. Rytov.1949,

Vol.3, ed. by S.M.Rytov.1950a,

Vol.4, ed. by M.A.Leontovich. 1955,

Vol.5, ed. by M.A.Leontovich. 1950b.

Mandelstam L.I.: “Ueber gerichtete drahtlose Telegraphie”. *Jahrbuch der drahtlosen Telegraphie und Telephonie*, 1908, Bd. 1, s.291-306.

Mandelstam L.I.: “Voprosy elektricheskikh kolebatel’nykh system i radiotekhniki <<Issues in Electrical Oscillators and Radio-Engineering”. *Uspehi fisicheskih nauk*. 1933, vol.13 , pp.161-194.

Mandelstam L.I., Tamm I.E.: “Sootnoshenie neopredelennsti energii-vremeni v nerelativistskoi kvantovoi mekhanike”. *Izvestia AN SSSR*, seria fiz.. 1945a, No.:2, pp.122-128.

Mandelstam L.I., Tamm I.E.: “The Uncertainty Relation between Energy and Time in Non-relativist Quantum Mechanics”. *Journal of Physics (USSR)*. 1945b, vol. 9, pp.249-254.

Mises R. *Veroiatnost’ i statistika* <<Probability and Statistics>> Gos.Izd.: Moscow, Leningrad 1930.

Mises R.von: *Positivism. A Study of Human Understanding.* Cambridge: Harv.Univ.Press, 1951.

Neumann I von: *Mathematische Grundlagen der Quantenmechanik*. Berlin: Verlag von Julius Springer, 1932, S.167.

Ovchinnikov Nikolai Fedorovich: *Poniatiia massi I energii v ikh istoricheskom razvitii I filosofskom znachenii*. Izd. Akademii Nauk: Moscow 1957.

Papalexy Nikolai D.: “Leonid Isaakovich Mandelstam”. In: [Mandelstam, 1948, pp.7-31].

Rytov Sergei M. (ed.): *Akademik Mandelstam. K 100 letiu so dnia rosjdeniia* << Academician L.I.Mandelstam. In commemoration of the 100th anniversary of birth>>. Nauka: Moscow 1979.

Sonin Alexandr Stepanovich: *Fizicheskii idealism: istoriia odnoi ideologicheskoi kompanii* <<Physical Idealism: the History of an Ideological Campaign>. Moscow: Nauka 1994.

Tamm Igor E.: “O rabotakh Mandelstama v teoreticheskoi fizike <<On L.I.Mandelstam's works in theoretical physics>>”. In: [Rytov (ed.), 1979, pp.131-137].

Tamm Igor E.: “On the Work of L.I.Mandelstam in Theoretical Physics”. In: I.E. Tamm: *Selected Papers*. Springer rlag: Heidelberg 1991, pp.270-276.

Van der Pol Balthasar: *Nelineinaia teoriia elektricheskikh kolebanii* <<The Non-linear Theory of Electric Oscillations>> Ed.: S.E.Khaikin. Sviaz'izdat: Moscow 1935.