PROBABILITY, MARXISM, AND QUANTUM ENSEMBLES

Alexei Kojevnikov

"And the physicist…
Is not a macro-instrument,
But a social phenomenon"

Gertsen Kopylov
"Evgeny Stromynkin," a novel in verse
circa 1950

ABSTRACT

This paper establishes a historical and philosophical link between two fundamental twentieth-century scientific debates: the search for mathematical foundations of probability theory and the controversy about the interpretation of quantum theory. Marxist philosophy played a heuristic role in Khinchin's approach to probability theory as a science of mass phenomena that also served as the background for Kolmogorov's axiomatic definition of probability. Understanding the distinction between statistics and indeterminism was important for Blokhintsev's Marxism-inspired "ensemble interpretation" of quantum mechanics, which also relied on Mandelstam's solution of the Einstein-Podolsky-Rosen paradox. These two related cases reveal in a different light the intricacy of the relationships between developments in the mathematical sciences and philosophical/ideological assumptions and arguments.

INTRODUCTION

In an important article published twenty years ago, Andrew Cross called attention to the long overlooked contribution of Marxist science to the fundamental problem of the interpretation of quantum theory.[1] After the last high-profile debate between Albert Einstein and Niels Bohr in 1936, open expressions of disagreements with the mainstream Copenhagen interpretation became rare. Its "almost unchallenged monocracy"[2] appeared unquestionable until around 1950, when a new wave of critical discussions reopened earlier issues and put forward new ideas. This time the impetus came from the Soviet Union in the form of a politically

1 Andrew Cross, The Crisis in Physics: Dialectical Materialism and Quantum Theory, in: Social Studies of Science 21 (1991), p. 735–759.
2 Max Jammer, The Philosophy of Quantum Mechanics: The Interpretation of Quantum Mechanics in Historical Perspective. New York 1974, on p. 250.

inspired campaign against idealistic and positivistic philosophies of modern science. Responding to this ideological call, Communist-leaning scientists in several countries criticized certain aspects of the Copenhagen interpretation and looked for corrections. Their concerted efforts provided stimulus also to some non-Marxist critics, such as Louis de Broglie, to join in the debate.[3] The discussion brought to physicists' attention several possible alternatives to the Copenhagen interpretation, in particular the statistical ensemble interpretation propagated by Dmitry Blokhintsev and David Bohm's causal theory with "hidden variables."

Olival Freire Jr., who pioneered the topic independently, pointed out that some aspects of Cross' analysis asked for correction. Freire in particular described the influential tradition within Marxist thought that, instead of looking for major alternatives to complementarity, formulated versions of the Copenhagen interpretation that were closer to materialism. To such Marxist physicists as Paul Langevin (1872–1946) in France, Vladimir Fock (1898–1974) in the USSR, and Mituo Taketani (1911–2000) in Japan, the philosophical lesson of quantum theory did not mean a wholesale rejection of causality, but a welcome departure from the simplistic, old-fashioned "mechanical determinism" towards a richer understanding of causal relations in nature.[4] With further studies by Anja Skaar Jacobsen and Christian Forstner, an entire spectrum of Marxist approaches to the problem of quantum interpretation has been analyzed: from the stalwart defender of the Copenhagen solution and Bohr's chief spokesman Léon Rosenfeld to Bohm's alternative "quantum potential," inspired by Hegelian dialectics and Lenin's analysis of the crisis in physics.[5] Clearly, there was no such thing as the "party line" in quantum philosophy, even if some Communist or anti-Communist authors wishfully assumed its existence.

Cross' presentation of the Soviet part of the debate, however, has not yet received critical revision. One obvious problem lies in its limited source base. Cross was able to describe the selected Soviet publications that were translated into French or German, perceptions of Soviet opinions elsewhere, primarily among the French Marxists, and the international impact they had during the 1950s. But for describing the situation in the Soviet Union proper, he had to rely heavily on the available secondary literature coming from the Cold War era. The resulting pic-

3 Louis de Broglie, La physique quantique restera-t-elle indéterministe? Paris 1953.

4 Olival Freire Jr., Comment on 'The Crisis in Physics', in: Social Studies of Science 22 (1992), p. 739–742; Olival Freire Jr., Quantum Controversy and Marxism, in: Historia Scientarum 7 (1997), p. 137–152. For another example of the distinction between determinism and causality in Marxist thought, see Christopher Caudwell, The Crisis in Physics. London 1939.

5 Anja Skaar Jacobsen, Léon Rosenfeld's Marxist defense of complementarity, in: Historical Studies in the Physical and Biological Sciences 33 (2007), p. 3–34; Christian Forstner, Dialectical Materialism and the Construction of a New Quantum Theory: David Joseph Bohm, 1917–1992, Preprint 303, Max-Planck-Institut für Wissenschaftsgeschichte, Berlin 2005; subsequently published in Minerva 46 (2008), p. 215–229. For other Marxist influences on Bohm's work in plasma and solid-state physics see: Alexei Kojevnikov, David Bohm and Collective Movement, in: Historical Studies in the Physical and Biological Sciences 33 (2002), p. 161–192.

ture became infused with propagandistic clichés about the hostile relationship between the Soviet ideology and science, such as, that Soviet authorities believed "good science could not be produced by physicists under a capitalist regime," or envisioned "a 'socialist' science distinct from the bourgeois Western science," or even that "quantum theory and relativity generated the strongest threat to Leninist epistemology."[6]

Here is not the place to discuss at length why such crude misperceptions continue to exist and sometimes appear in the literature even now – long after the end of the Cold War. Suffice it to say that both relativity theory and quantum mechanics received an enthusiastic and early reception in the Soviet Union and were very quickly elevated to the standard and core components of university curriculum. A few active opponents of the new physics existed, but did not enjoy much support either among the physics community or from the political authorities, and their dissenting voices were only rarely heard or published. The authorities did desire, however, Marxist interpretations of basic scientific theories and called on Soviet physicists and philosophers to develop them. One should not rush to conclude with many today's commentators that Marxist references in the works of Soviet scientists can thus be disregarded as either forced or insincere. This would make us overlook many instances when the use of Marxist ideas made sense to scientists, including important cases when those ideas contributed to the development of novel scientific concepts and interpretations – which is precisely the example discussed in this paper.

In subsequent sections, I will focus primarily on the emergence of the collectivist, or ensemble interpretation of quantum mechanics in the 1930s–1950s Soviet Union, which can be briefly summarized as follows. The fundamental laws of quantum mechanics are probabilistic ones, and necessarily so, because they describe the behaviour of large collectives, "ensembles," rather than an individual atom or electron. This is so not only in the obvious cases of many-particle systems. Even when quantum mechanics appears to be talking about one individual particle, a careful analysis of the experimental situation can demonstrate that it actually deals with many atomic systems in a similarly prepared state, or with many repeated experiments of the same setup. One should not conclude that quantum mechanics is deficient – it is as good as the usual statistical mechanics, each perfectly justified in their respective domains of validity – nor that it is reducible to statistical mechanics, because their laws are different. The question of whether another theory is possible, one capable of describing an individual atom or electron, and whether or not such a description can be deterministic, was not answered by the ensemble interpretation, but left open to further development of science. What it did achieve, is that such puzzles as the Einstein-Podolsky-Rosen paradox, which often bewilder us when we think about the behaviour of quantum particles

6 Cross, op. cit., p. 737–739; the main source appears to be A. Vucinich, Soviet physicists and philosophers in the 1930s: dynamics of a conflict, in: Isis 71 (1980), p. 236–250.

as individuals, could be resolved once it is understood that the experimental setup involves large collectives.[7]

The first part of this paper examines the early roots of the statistical ensemble concept in the 1930s, especially the probability theory and its Marxist justification. I will then turn to the ideologically provoked postwar debates about quantum interpretation and the range of possible opinions they revealed (there was no “party line” on quantum philosophy even in the Soviet Union). And finally, the paper will consider Blokhintsev’s path towards the full exposition of the ensemble interpretation in his 1949 textbook and related articles, leading to the concluding discussion about the intricate relationship between dialectical materialism and quantum physics in the Soviet Union. Among the publications cited below, Aleksandr Pechenkin’s philosophical discussion of various statistical interpretations and Aleksandr Kuzemsky’s review of Blokhintsev’s scientific publications, were especially helpful for the following analysis.

PROBABILITY VS. ACAUSALITY

Probability theory provided an important source and inspiration for the subsequent development of the ensemble interpretation of quantum mechanics. Philosophical and ideological currents were at play in pure mathematics, as they were in physics, as can be seen in the work of the founder of the Moscow school on probability theory, Aleksandr Khinchin (1894–1959) and his polemics with the Austrian-German-American mathematician Richard von Mises (1883–1953). In a series of influential publications during the 1920s, von Mises proposed a fundamental reconsideration of the probability theory, whose mathematical foundations had not changed much since Laplace in the early nineteenth century, despite all the advances in its methods and applications. Von Mises considered the classical definition of probability, resting on the a priori concept of equally possible outcomes, indefensible on both philosophical and mathematical grounds. Instead, von Mises proposed to define probability empirically, in the spirit of Mach’s positivism, as the frequency of a particular outcome in a long series of experimental tests.[8]

Khinchin wholeheartedly supported von Mises’ devastating critique of the classical definition and his general assessment of the miserable situation with the foundations of the probability theory, but the Soviet mathematician disagreed with the proposed positivistic solution on both philosophical and mathematical

7 The above summary is based on original primary sources. For modern versions of the ensemble interpretations see L. E. Ballentine, The Statistical Interpretation of Quantum Mechanics, in: Reviews of Modern Physics 42 (1970), p. 358–381, and discussions in: D. Home, M. A. B. Whitaker, Ensemble interpretation of quantum mechanics: a modern perspective, Physics Reports 210 (1992), p. 225–317; L. E. Ballentine, Can One Detect the State of an Individual System? in: Foundations of Physics 22 (1992), p. 333–342.

8 Richard von Mises, Grundlagen der Wahrscheinlichkeitsrechnung, in: Mathematische Zeitschrift 5 (1919), p. 52–99; Richard von Mises, Warscheinlichkeit, Statistik und Wahrheit. Wien 1928.

grounds. Khinchin developed probability theory in a series of influential publications starting 1924. He defined the latter as a mathematical discipline, rather than an empirical science, explaining the difference materialistically: a natural science is distinguished by the specific class of material objects it studies, whereas mathematics can treat objects of heterogeneous material nature, because it abstracts and focuses on their common formal properties. Instead of a superficial positivistic definition, the fundamental way of sorting out the foundations of the probability theory, according to Khinchin, required designing an appropriately mathematical axiomatic structure.

Khinchin agreed with von Mises that the fundamental object of the probability theory was a collective of any kind, but multiple in numbers: "The theory of probability is a science of mass phenomena. Its methods are only applicable to real events in which a large number of similar constituent entities take part. Its main concept refers to the relative proportion of these entities that possess a certain common feature, whereas the actual material nature of these entities lies outside the scope of investigation in the theory of probability."[9] From the above, he derived a logical conclusion that directly opposed von Mises' belief in indeterminism at the individual level. Strictly speaking, according to Khinchin's definition it is not justifiable to use the mathematical notion of probability when discussing an individual event. For example, even if my personal future is uncertain, there is no such thing as a mathematical probability for me to die tomorrow, but there is a probability for, say, sixty people to die the following day in a metropolitan city like Vancouver. At the same time, the validity of probabilistic laws for collectives can coexist with causal behaviour at the individual level. Even if individuals are described deterministically by some other science, explained Khinchin, the probability theory can still be applicable to the properties of a large collective of them, because of the way it abstracts certain features for its kind of analysis.[10]

Khinchin mentioned in a footnote, with a tone of disapproval, the existence of "radical" acausal views with regard to atomic phenomena, but he did not engage explicitly the topic of quantum physics.[11] In developing his views on the theory of probability, he collaborated with his student and younger colleague at Moscow University, mathematician Andrei Kolmogorov (1903–1987), with physicists

9 A. Ya. Khinchin, Chastotnaia teoriia R. Mizesa i sovremennye idei teorii veroiatnostei. The paper dates from around 1940, but was first published posthumously, in: Voprosy filosofii (1961) #1: p. 92–102; #2: p. 77–89, and more recently reprinted in A. Ya. Khinchin, Izbrannye Trudy po Teorii Veroiatnoistei (Moscow 1995), p. 517–552, citation on p. 525. For an English translation and further historical commentary, see: Reinhard Siegmund-Schultze, Mathematicians forced to philosophize: An introduction to Khinchin's paper on von Mises' theory of probability, in: Science in Context 17 (2004), p. 373–390.

10 For an explicit model of deterministic chaos, or a deterministic mechanical system behind a gambling game, see: A. Ya. Khinchin, Metod proizvol'nykh funktsii i bor'ba protiv idealizma v teorii veroiatnostei, in: Filosofskie Voprosy Sovremennoi Fiziki. Moscow 1952, p. 522–538.

11 A. Ya. Khinchin, Uchenie Mizesa o veroiatnostiakh i printsipy fizicheskoi statistiki, in: Uspekhi fizicheskikh nauk 9 (1929), p. 141–166, on p. 161.

from the neighbouring department Leonid Mandelstam and Mikhail Leontovich (1903–1981), and with the Marxist philosopher Boris Gessen (1893–1936) from the Communist Academy. Kolmogorov in 1933 succeeded in formulating the system of axioms that placed the mathematical theory of probability on a modern footing and has become generally accepted as the foundation of the field in contemporary mathematics.[12] Gessen (better known in English among historians of science as Boris Hessen, the author of the *Social and Economic Roots of Newton's Principia* (1931)) developed the corresponding philosophical, dialectico-materialist, analysis of the (classical) statistical mechanics and its problems.[13] It would be left for physicists in this circle to apply similar ideas to the interpretation of quantum physics.

Another source, and an immediate inspiration for them to do so, came from the debate between Einstein and Bohr regarding the 1935 Einstein-Podolsky-Rosen paradox and the description of physical reality, which was translated into Russian and followed with great attention by Soviet physicists. One of Einstein's remarks resonated in their midst: Einstein, like several other physicists on various occasions, mentioned that the EPR paradox could be resolved if one accepted that "the ψ function does not, in any sense, describe the condition of *one* single system… it relates rather to many systems, to 'an ensemble of systems' in the sense of statistical mechanics."[14] Einstein did not follow through with his suggestion, however, but instead took it to signify that quantum mechanics was incomplete, and continued to long for a better, fuller, description at the individual level. Soviet physicists took up the idea much more seriously, as a way to sort out systematically the difficulties in the interpretation of quantum mechanics and, in particular, avoid fundamental acausality.

A young theoretical physicist Konstantin Nikolsky (1905–1978) started doing just that in his 1936 paper "The principles of quantum mechanics. I." Quantum mechanics to him was a non-classical statistical theory. He formulated its laws as describing ensembles of particles and analyzed mathematically the differences between the statistical description in the classical and the quantum version. In the

12 A. Kolmogorov, Grundbegriffe der Wahrscheinlichkeitsrechnung. Berlin 1933. For recollections about Khinchin's and Kolmogorov's joint seminar on the probability theory in the 1930s, see B. V. Gnedenko, Uchitel' v matematike, uchitel' v zhizni, in: Yavlenie chrezvychainoe. Kniga o Kolmogorove. Moscow 1999, p. 40–48. The mathematical context and reception of Kolmogorov's breakthrough are discussed by Glen Shafer and Vladimir Vovk, The sources of Kolmogorov's Grundbegriffe, in: Statistical Science 21 (2006), p.70–98.

13 B. M. Gessen, Teoretiko-veroiatnostnoe obosnovanie ergodicheskoi gipotezy, in: Uspekhi fizicheskikh nauk 9 (1929), p. 600–629; B. M. Gessen, Statisticheskii metod v fizike i novoe obosnovanie teorii veroiatnosti R. Mizesom, in: Estestvoznanie i Marksizm (1929), # 1, p. 3–58.

14 A. Einstein, Physics and Reality, in: Journal of the Franklin Institute 221 (1936), p. 349–382, on p. 375. For additional quotations pointing to the ensemble interpretation and discussion, see: Max Jammer, The Philosophy of Quantum Mechanics: The Interpretation of Quantum Mechanics in Historical Perspective. New York 1974, 440–447; L. E. Ballentine, Einstein's interpretation of quantum mechanics, in: American Journal of Physics 40 (1972), p. 1763–1771.

latter case, the finiteness of the Planck quantum meant that the statistical properties of the ensemble changed in the process of measurement, through interaction with macroscopic measuring devices, whereas at the classical level such interaction could be considered negligible. The statistical reformulation of quantum laws preserved this uncertainty in measurement, concluded Nikolsky, but it allowed physicists to "characterize quantum processes as objective ones,"[15] whereby the probabilities of experimental outcomes corresponded not to indeterminacy in individual behaviour, but to objective probabilities – the relative number of particles within a quantum ensemble for which the measured variable had a particular value.

Nikolsky's proposal encountered an immediate opposition from the leading quantum theoretician in the Soviet Union and the author of the first textbook on the topic in Russian, Vladimir Fock.[16] In his letter to the journal, Fock argued that Nikolsky's formulae implicitly contained the usual postulates of the quantum theory and thus the latter's meaning did not have to change: "A reader of Nikolsky's article might get an impression that quantum mechanics is merely a form of statistics. But the fundamental achievement of modern physics is that it learned to observe elementary physical processes, individual particles... The language of quantum mechanics allows the description of an individual measurement. Even though the predictions of quantum mechanics are usually statistical… it cannot be reduced to statistics."[17]

In his response to Fock's criticism, Nikolsky drew the ideological line. He pointed out that there were more than one existing interpretations of quantum mechanics, including those by Einstein and Schrödinger, and referred to his statistical proposal as representing Einstein's stance on the issue. "In order to achieve a materialistic description, it is necessary to represent physical events objectively, in space and time, as existing independently from the observer… Quantum mechanics in Bohr's interpretation does not satisfy this condition," wrote Nikolsky. The quotes he used for illustration, regarding the indeterminate behaviour of atomic particles as depending on the observer, actually came from Werner Heisenberg's rather than Bohr's philosophizing. Nikolsky argued that Fock and other proponents of the "Copenhagen school" in the Soviet Union should stop masquerading this interpretation as compatible with materialism and try, instead, to develop a "truly materialistic theory of atomic phenomena."[18] In proofs, he added a reference to the most recent "positivistic" representation of quantum mechanics by Pascual Jordan in Germany. When Fock read Jordan's book, he, too, became extremely alarmed and outraged by its attempt to represent the Copenhagen interpre-

15 K.V. Nikol'skii, Printsipy kvantovoi mekhaniki. I, in: Uspekhi fizicheskikh nauk 16 (1936), 537–565, on p. 540.

16 V. A. Fok, Nachala kvantovoi mekhaniki. Leningrad 1932.

17 V. A. Fok, K stat'e Nikol'skogo 'Printsipy kvantovoi mekhaniki,' in: Uspekhi fizicheskikh nauk 17 (1937), p. 552–554, on p. 554.

18 K. V. Nikol'skii, Otvet V. A. Foku, in: Uspekhi fizicheskikh nauk 17 (1937), p. 554–560, on pp. 555, 557.

tation as compatible with the Nazi ideology, and broke relations with the author with whom he had once collaborated in writing physical papers.[19]

In part, a generational difference was at play in this disagreement between the teacher and his former student. Nikolsky learned quantum mechanics from Fock at the same time while he was also learning Marxism from his other university professors. He took both doctrines equally seriously and was prepared to change the existing philosophical interpretation of the laws of quantum mechanics to satisfy dialectical materialism. Fock personally participated in the creation of quantum mechanics, starting 1926, and he learned dialectical materialism during the following decade, already a distinguished scientist in his own right. He took Marxism very seriously, too, but also felt a strong personal loyalty towards Bohr, if not Heisenberg. Instead of replacing the Copenhagen interpretation, Fock always preferred to change its wordings slightly in order to make it compatible with Marxism. His status as a scientist was much higher than Nikolsky's, and the latter's intended continuation of the article never appeared in the journal. But Nikolsky did not abandon the project: he developed the statistical proposal further in the book *Quantum Processes*, published several years later.[20] Blokhintsev would subsequently use Nikolsky's ensemble treatment of the wave function reduction in the 1949 textbook.

Similar ideas were germinating within the circle of Moscow physicists, including the much more senior and authoritative Leonid Mandelstam (1879–1944). Educated before the revolution, Mandelstam was no Marxist either politically or philosophically – he tried to stay away from any ideological discourse, while his views in physics lay close to operationalism. On the matter of probability and causality, he was more sympathetic to von Mises than his younger and politically more engaged colleagues among mathematicians, physicists, and Marxist philosophers. At the same time, he collaborated with the latter, in particular with Khinchin and Gessen on the foundations of statistical mechanics, and very likely also with Nikolsky during the second half of the 1930s, when both worked at the Physical Institute of the Academy of Sciences in Moscow. In 1939 he applied the statistical ensemble idea to sort out the difficulties in the interpretation of the famous thought experiments that lay at the foundation of quantum physics.[21]

Mandelstam's ability to do Nobel-level research in physics contrasted sharply with his quiet and unimposing demeanour and aversion towards publicity or power in the academic world, which partly accounts for the fact that he received less outward recognition than he deserved. His intuition and private advice on difficult questions in physics, however, were highly sought after by many of his well-

19 Pascual Jordan, Anschauliche Quantentheorie. Berlin 1936; Fock to Jordan, Fock Collection, Archive of the Russian Academy of Sciences, St. Petersburg. On Fock's collaboration with Jordan see: A. B. Kozhevnikov, V. A. Fok i metod vtorichnogo kvantovaniia, in: Issledovaniia po istorii fiziki i mekhaniki 1988. Moscow 1988, p. 113–138.

20 K. V. Nikol'skii, Kvantovye protsessy. Moscow 1940.

21 For Mandelstam's biography and a detailed analysis of his philosophical views, see A.A. Pechenkin. Leonid Issakovich Mandel'shtam: Issledovanie, prepodavanie i octal'naia zhizn'. Moscow 2011.

established scientific colleagues, many of whom were influenced by his thinking and approach by way of backroom consultations. Although quantum physics was not his primary field of research, Mandelstam coauthored an important paper during the creation of quantum mechanics, predicting the possibility of quantum tunnelling under the potential barrier. With another collaborator, he co-discovered in 1928 the quantum optical effect usually known as the Raman Effect, since it was also simultaneously and independently found by C.V. Raman.[22] During the 1930s Mandelstam and his coworkers were mainly occupied with creating a new field of non-linear physics, but the debate between Einstein and Bohr drew his attention to the fundamental problem of quantum interpretation.

Mandelstam developed his views on the EPR controversy in an advanced lecture course on "The Foundations of Quantum Mechanics (The Theory of Indirect Measurement)" taught at Moscow University in the spring of 1939, but did not publish them. His students prepared the surviving texts of his colloquia notes for print in 1950, in the final volume of Mandelstam's collected works, published posthumously. Like a number of early pioneers of the ensemble approach, Mandelstam was influenced by von Neuman's 1932 mathematical analysis of the foundations of quantum mechanics which, as Max Jammer observed, was written "with the general tenor of the statistical ensemble interpretation."[23] Von Neumann's influence would eventually make the very term "ensembles" the typical word of choice for quantum physicists, whereas their mathematical colleagues, such as von Mises and Khinchin, spoke of "collectives." The "general tenor" refers only to the mathematical language of the book, perfectly adaptable to analyse statistical ensembles, but definitely not to its philosophical conclusions. Von Neumann believed that quantum mechanics described individual processes and that he had proven "the impossibility of a causal atomic theory," whereas Mandelstam was not at all convinced by that proof.

In his analysis of the EPR paradox, Mandelstam was torn between his equal reverence towards Einstein and Bohr. In the end, one can say that he found a third way out of the challenging dilemma as formulated by Einstein: either quantum mechanics was an incomplete, or a mysteriously non-local theory. If one systematically follows through with the suggestion that in quantum mechanics, "physical parameters (observables) refer to populations, rather than individual cases," and that quantum measurement acts upon a statistical "collective," explained Mandelstam, the EPR paradox ceases to be a paradox and does not require the two spatially separated systems I and II to interact instantaneously. The interaction had happened earlier, before the separation, while subsequent measurements select different sub-populations from an ensemble of such pairs of systems after their

22 L. Mandelstam, M. Leontowitsch, Zur Theorie der Schrödingerschen Gleichung, in: Zeitschrift für Physik 47 (1928), p. 131–136; L. Mandelstam, G. Landsberg, Eine neue Erscheinung bei der Lichtzerstreuung in Kristallen, in: Die Naturwissenschaften 10 (1928), p. 557–558, p. 772.

23 Max Jammer, The Philosophy of Quantum Mechanics: The Interpretation of Quantum Mechanics in Historical Perspective. New York 1974, on p. 443; Johann v. Neumann, Mathematische Grundlagen der Quantenmechanik. Berlin 1932.

interaction. "Once I understood the mistake, I could no longer see and present the matter in any other way," confessed Mandelstam. "The essence of the problem is that when we are performing different measurements on system II, we are selecting different subsets… For each subset separately, the uncertainty relation holds for system I… But nothing prevents us from measuring exactly the [two non-commuting observables] from two different subsets."[24] Even before the publication of Mandelstam's lectures in 1950, the essence of his argument was known, at least in Moscow, to the circle of interested physicists, including Blokhintsev, who used and cited Mandelstam's still unpublished analysis of the EPR in his 1949 textbook.

In 1941–1945, Soviet physicists were mostly occupied with research related to the war effort, and when some of them returned to questions of quantum interpretation at the war's end, the discussion resumed in a very different political and ideological situation.

ATTEMPTS AT IDEOLOGICAL CLARITY

Andrei Zhdanov (1896–1948) was a career politician with a reputation as an intellectual within party circles, who served the party in various offices overseeing ideology and/or arts and culture. In 1946–48 he briefly became one of the most influential members of the Soviet Politburo, with an assignment to preside over the Central Committee Secretariat. His ascendance also meant the rise in the perceived political importance of the ideological and cultural policies he dealt with, and resulted in, among other things, a series of high-profile and highly ideological discussions in various branches of scholarship. The first of such meetings, not surprisingly, concerned philosophy: the most politicized academic field in which the responsible party officials could perform as experts. The immediate purpose of the philosophical discussion in June 1947 was to critically review and correct the official Soviet textbook on the history of philosophy. As befitted a politician, Zhdanov elevated the topic in his concluding remarks to a higher political significance: he scolded the community of Soviet philosophers for their general dogmatism and complacency, urged them to be more critical and self-critical, more creative in the development of Marxism, and more militant in fighting against

24 L. I. Mandelshtam, Lektsii po osnovam kvantovoi mekhaniki (teoriia kosvennykh izmerenii) (1939), in: Lektsii po optike, teorii otnositel'nosti i kvantoivoi mekhanike. Moscow 1972, p. 325–388, on pp. 332–333, 363–364. For a philosophical analysis of Mandelstam's interpretation, see A. A. Pechenkin, Statistical interpretation of quantum mechanics in L. I. Mandel'shtam's lectures and its ideological environment," Phystech Journal 2 (1996), p. 70–81; A. A. Pechenkin, Mandelstam's interpretation of quantum mechanics in comparative perspective. International Studies in the Philosophy of Science 16 (2002), p. 265–284.

bourgeois ideology.[25] Only one paragraph in Zhdanov's talk directly concerned physics and physicists, but it did generate some confusion.

Bourgeois philosophers and scientists, warned Zhdanov, misinterpreted science in the service of religion and philosophical idealism. By name he mentioned only two British astronomers – Arthur Eddington (1882–1944) and Arthur Milne (1896–1950) – who were, indeed, openly arguing for a version of creationist science by linking Einstein's relativity and cosmology to God and, as such, provided familiar and easy targets for Soviet critics. "In the same measure, – continued Zhdanov – Kantian deviations of modern atomic physicists lead them to statements that electrons possess "free will" and to the attempts at depicting matter as merely a superposition of waves, and to other apparitions… Soviet philosophers must analyze the achievements of modern science following Engels' dictum that 'materialism has to take a new form with every landmark great discovery of the natural sciences'."[26]

The vagueness of Zhdanov's remarks reflected his limited knowledge of physics and prompted one of his aides, Sergei Suvorov (1902–1989?), the acting head of the Central Committee science section and a physicist by education, to send him a note warning that his use of the phrase "superposition of waves" "can be easily misinterpreted… since the text does not explain clearly what is actually criticized. Contemporary physics has shown that various physical fields – electromagnetic, gravitational, possibly also meson – exist that… constitute a form of matter… There are still some among physicists who oppose modern physics and deny its achievements. Ignoring facts, they are rejecting the theory of relativity and quantum mechanics… These philosophical and physical retrogrades will certainly try to use such phrase claiming that "the Central Committee supports" their rejection of physical fields as one of the forms of matter."[27]

It would actually be Western Sovietologists who happily misrepresented Zhdanov's phrase as a proof that Soviet ideology opposed quantum mechanics. Soviet physicists and philosophers knew better that – notwithstanding few remaining marginalized grumblers – quantum mechanics was doing just fine. It had been enthusiastically accepted in the Soviet Union twenty years earlier, and by the 1940s was not even a novelty anymore, but a standard research tool and lecture topic in all universities. With its usefulness and empirical validity fully recognized, quantum mechanics never came in doubt during the ensuing discussions. Its philosophical interpretations, however, were debatable, and as a commonplace, Soviet authors distinguished, following the paradigm of Lenin's *Materialism and Empiriocriticism*, between the great advances of science, on the one hand, and on the other hand, the often "wrong" or "misleading" philosophical labels attached to

25 On this and other postwar debates in Soviet sciences, see: Alexei Kojevnikov, "Games of Stalinist Democracy: Ideological Discussions in Soviet Sciences, 1947–52," in: Sheila Fitzpatrick (ed.), Stalinism: New Directions (Rewriting Histories). London 2000, p. 142–175.

26 Diskussiia po knige G. F. Aleksandrova 'Istoriia zapadnoevropeiskoi filosofii,' p. 16–25 iiunia 1947 g. Stenograficheskii otchet, in: Voprosy filosofii (1947) #1, on p. [371].

27 Cited in V. D. Esakov, K istorii filosofskoi diskussii 1947 g., in: Voprosy filosofii (1993) # 2: p. 85–106, on pp. 95–96.

them by some commentators, or even by the discoverers themselves. As one of the harshest Soviet critics of Einstein expressed it, "Einstein is a big scientist, but a shallow philosopher," possibly paraphrasing Einstein's own self-deprecating remark of 1936 or Lenin's remark about Henri Poincaré in 1909.[28]

Where exactly to draw the boundary between the accepted science of quantum mechanics and its debatable interpretation could fluctuate, depending on the position of the writer, as quickly became apparent in the debate that followed. The immediate consequence of Zhdanov's speech was the establishment of the professional philosophical journal *Voprosy Filosofii,* the first issue of which printed verbatim the proceedings of the 1947 meeting. The second issue heeded Zhdanov's call and opened the discussion on philosophy of physics with the publication of an article "On the nature of physical knowledge" by Moisei Markov (1908–1994). "Our philosophical literature has not yet carefully analyzed the principal issues of quantum theory… But quantum theory is already a quarter century old and excellently verified by the experiment in its domain of validity… We will take the theory in its current form… within the limits of the physical concept of complementarity… and discuss the possibility of a consistently materialistic elucidation of this concept," defined Markov the aim of his essay.[29]

Markov remained as true to Bohr as possible in his interpretation, with only a few changes in some sensitive words that sounded too "subjective" for materialist taste. He explained how physicists defined their fundamental concepts via operational procedures of measurement and using thought experiments, the necessity of studying microscopic processes through their interaction with macroscopic devices of complementary types, and how the notions of classical physics became limited in the microscopic domain by the uncertainty relations (suggesting "imprecision" as a better, less provocative name than "uncertainty"). Markov substituted phrases "uncontrolled disturbance" and "the impact of the observer" with: "The physical reality of quantum theory… includes an element of active human work, which projects the microscopic reality onto the sphere of direct cognitive activity of a macroscopic organism," and the human observer, to him, was "in his physical capacity, a macro-instrument." He called the laws of quantum mechanics "probabilistic" rather than "acausal," argued that the theory was complete within its domain of validity, and expressed scepticism regarding the ensemble and hidden variables proposals.

Despite the endorsement by the Academy of Sciences' president Sergei Vavilov (1891–1951) and the fact that Markov garnered enough quotations from Marx, Engels, and Lenin in support of his claims, his adaptation of the Copenhagen interpretation ultimately proved too bold for Soviet Marxists of the 1940s. The initial round of responses was rather positive, but the following year, the editors of *Voprosy Filosofii* changed, and the new editorial board launched a much

28 M. M. Karpov, Kritika filosofskikh vzgliadov A. Einshteina, in: Filosofskie voprosy sovremennoi fiziki. Moscow 1952, p. 216–233, on p. 231.

29 M. A. Markov, O prirode fizicheskogo znaniia, in: Voprosy filosofii (1947) #2: p. 140–176, on p. 142.

more militant discussion on the pages of the journal, in which Markov was mainly scolded for not sufficiently criticizing Heisenberg's and Bohr's idealistic pronouncements, but merely window-dressing their philosophy as materialism. One of the discussants declared complementarity unnecessary, since quantum mechanics could easily "get along without it."[30]

Heisenberg's and Jordan's openly idealistic philosophical comments about quantum mechanics were the poster examples for ideological critique in Soviet writings of the 1940s, especially Jordan's publicized claim that "quantum mechanics had disproved materialism" and Heisenberg's phrases about the impact of the "observer" on measurement, "uncontrolled disturbance," and the mathematical description of quantum processes as occurring "outside space and time." Bohr also made some idealistic statements, but since he was revered almost as much as Einstein by so many Soviet physicists and philosophers, open attacks on him were less common. Some authors tried to avoid mentioning Bohr by name when expressing their disagreements with the Copenhagen interpretation. But even despite the reluctance of many physicists to criticize Bohr, Markov's attempt to incorporate complementarity into the body of the accepted physical theory of quantum mechanics did not succeed at the time. The most active discussants classified complementarity as a statement about philosophical interpretation, not part of the physical theory proper, and thus a legitimate target for criticism.[31]

An attempt to draw the boundary in a different way appeared in the famous *Course of Theoretical Physics* by Lev Landau (1908–1968) and Evgeny Lifshitz (1915–1985). Their volume on (non-relativistic) quantum mechanics came out as the first edition in 1948. Heisenberg's indeterminacy relation (expressed by the canonical mathematical formula) occupied a prominent place in the Landau-Lifshitz presentation, furnished with a complete derivation and a proper credit to the author. Complementarity, however, was not even mentioned by name. In part because it did not have a mathematical representation and in part because it was being criticized as idealistic, Landau and Lifshitz chose to ignore it altogether, along with all the rest of philosophical hand-waving about quantum theory. They merely mentioned in the introduction that, unlike the situation in classical physics, the state of an atomic system changes during the process of measurement due to the interaction with the measuring device. In so doing, they carefully avoided the adjective "uncontrolled" and stressed more than once that by measurement, no "observer" was meant, but "a process of interaction between a quantum and a classical object that occurs objectively, independently of any observer."[32]

30 "Obsuzhdenie stat'i M. A. Markova," Voprosy filosofii (1947) #2, p. 140–176; (1948) #3, p. 212–35, on p. 229.

31 Philosophical seminars at Moscow University, where Markov's paper was criticized, were satirically described by the student poet Gertsen Kopylov in the poem "Evgeny Stromynkin" quoted above, in the epigraph to this paper. It refers to Markov's characterization of the observer as a "macro-instrument."

32 L. Landau, E. Lifshits, Kvantovaia mekhanika. Chast' I. Nereliativistskaia teoriia. Moscow-Leningrad 1948, on p. 13.

Such a minimal rhetorical adaptation – including the indeterminacy relation, but no complementarity (at least not explicitly), and replacing "observer" with an "instrument" – would become a popular, acceptable, and long-lasting way of teaching the science of quantum mechanics to students in the Soviet Union, and in this respect the option taken by Landau and Lifshitz represented the mainstream solution. What was untypical of it, by the standards of the 1940s–50s, was the absence of any explicit invocation of "dialectical materialism," or any other philosophy for that matter. This was clearly an act of defiance: although the ideological authorities neither chose by themselves nor prescribed any particular interpretation of quantum mechanics to physicists, they strongly urged Soviet scientists to become actively and openly engaged with philosophy, especially when writing popular articles and textbooks. A typical Soviet textbook of the period was expected to include at least a critical remark about the existing "idealistic" interpretations by some Western authors and a favourable reference to dialectical materialism. Landau chose to ignore the call.[33]

Dmitry Blokhintsev, the author of another textbook, *Foundations of Quantum Mechanics*, which came out in a thoroughly revised second edition in 1949, did exactly what Soviet physicists were urged to. He actively discussed quantum philosophy, criticized idealistic versions, and attempted to develop an interpretation compatible with dialectical materialism, which subsequently became known in quantum theory as the "ensemble interpretation"[34]

BLOKHINTSEV AND QUANTUM ENSEMBLES

Dmitry Ivanovich Blokhintsev (1908–1979) studied physics at Moscow University in 1926–30, which coincided with a short period of revolutionary transformation in more than one sphere of life. In physics, the new quantum mechanics entered university courses for the first time – taught via original journal publications, since there were still no textbooks. The younger professors who introduced the novel subject captured students' imaginations; those older physicists who were still sceptical or harboured resentment got the reputation of retrogrades. The quantum revolution destroyed many traditional dogmas of physics; its radical vision could entice enthusiasm, bewilderment, and disbelief at the same time – but less disbelief when studied in the classroom. Bokhintsev belonged to the first generation of students who learned quantum mechanics in regular seminars, from their teachers, more or less systematically and as a concept that no longer had to be doubted, but mastered as a skill. This combined sense of intellectual excitement

33 Such demonstrative indifference to philosophy could, and on some occasions did become criticized by zealous commentators, but it was still less risky than the faux pas of expressing "idealistic" views.

34 D. I. Blokhintsev, Osnovy kvantovoi mekhaniki. Izdanie vtoroe, pererabotannoe. Moscow-Leningrad 1949.

and authority generated by the quantum theory stayed with him until the end of his life.[35]

Via a similar intellectual dynamics Marxism generated pretty much the same attitude among university students during that period of Soviet history, also known as the “cultural revolution” or the “great break.” As a revolutionary force, Marxism contradicted many of the old social dogmas and was destroying the traditional, rural and hierarchical society, transforming it into an industrial and socialist one. This radical change, and the vastly expanded and egalitarian system of higher education it produced, opened up previously unimaginable career opportunities to hundreds of thousands of young people, who flocked into the new and old colleges.[36] Dialectical materialism for the first time began to be taught as a new required course for all science and engineering students of that generation. Its teachers were often almost as young as the students themselves, while those among the older professors who still quietly resisted or harboured resentment were referred to as retrogrades. Marxist philosophy was taught authoritatively, as a skill to master, not to doubt, and as the belief that distinguished the young upcoming generation from the older folks. Blokhintsev, like many students of his class, was inspired by dialectical materialism. He interiorized it as seriously as he did quantum mechanics, and retained this commitment until the end of his life.

35 See his scientific autobiography: “Moi put’ v nauke (avtoreferat rabot)” in the 2-volume edition of selected works: D.I. Blokhintsev, Izbrannye Trudy. Moscow 2009, 1: p. 18–72

36 Sheila Fitzpatrick, Education and Social Mobility in the Soviet Union, 1921–1934. Cambridge 1979.

Picture 1. The physics class at Moscow University, 1929. Blokhintsev is in the second row, second from the left, in a cap. Markov is standing next to him, the tallest of all. Next to Blokhintsev on the other side is Ilya Frank (1908–1990), of later Nobel Prize fame. Sergei Vavilov, the professor, is sitting in the front row, to the right of Blokhintsev's future wife and colleague S. I. Drabkina. The other professor, Kliment Timiriazev, is cut off from the photo's right side. Students who published it later usually did not want to be seen as photographed together with a critic of Einstein.

In several academic controversies of the 1930s–40s, Blokhintsev took issue with those who pitted two emerging orthodoxies against each other, or opposed one or the other. He actively criticized continuing efforts by Nikolai Kasterin (1869–1947) and Vladimir Mitkevich (1872–1951) to develop ether-like vortex theories of electrons and photons along the lines suggested in 1925–1926 by J. J. Thomson (1856–1940) in Britain. To Blokhintsev, such desperate attempts in the style of classical physics by the retiring generation of scientists had been made obsolete by "modern quantum mechanics, which explains wave properties of particles without any recourse to vortices, or any other specific model."[37] In the conflict among Moscow University physicists, he sided with Mandelstam and others who opposed Kliment Timiriazev (1880–1955), a stubborn critic of relativity theory who fought his losing battle by citing both Marxist philosophy and American experiments, performed by Dayton Miller who claimed to have disproved Einstein. At the same time, Blokhintsev and his Marxist teacher F.M. Gal'perin defended the conservation of energy against some quantum physicists, including Bohr and Landau, who were willing to entertain the possibility of the principle's violation.[38] Soviet Marxists proclaimed energy conservation one of the basic pillars of materialism and strongly criticized any attempts to doubt it. Quantum mechanics' ultimate agreement with dialectical materialism on the fundamental question of energy conservation only strengthened Blokhintsev's belief in both.

As a graduate student, Blokhintsev matured professionally under the supervision of his physics teacher Igor Tamm (1895–1971), a close associate of Mandelstam and one of the leading quantum theorists in the Soviet Union. Blokhintsev's doctoral thesis of 1934 combined several of his published investigations in the quantum theory of the solid state. One aspect of that research series may have contributed to his subsequent preference for the ensemble interpretation: already in the 1930s, technical advances in solid state theory started developing contradictions with the assumed individuality of atomic description. The problem actually began much earlier, in the many-body problem in quantum mechanics, where the symmetry of wave function implied that quantum particles cannot be distinguished individually from one another. It became further complicated in condensed matter and in quantum field theory, systems with infinite degrees of freedom. Even in relatively simple problems in the theory of metals, Blokhintsev demonstrated, the electron mass was no longer the intrinsic characteristic of an individual particle, but varied depending on other particles and interactions – became "effective" or "apparent" mass.[39] His research contributed to the general development of "collective methods" in condensed matter physics, an approach

37 D. I. Blokhintsev, Otsyv o knige akademika V. F. Mitkevicha 'Magnitnyi potok i ego preobrazovanie,' (date uncertain, but prior to 1945), published in: Atomnyi Proekt SSSR. Dokumenty i Materialy. I. Chast' 2. Moscow 2002, p. 264–266.

38 D. Blokhintsev, F. Gal'perin, Bor'ba vokrug zakona sokhraneniia i prevrascheniia energii v sovremennoi fizike, in: Pod znamenem marksizma (1934) #3: 97–106; D. Blokhintsev, F. Gal'perin, Atomistika v sovremennoi fizike, in: Pod znamenem marksizma (1936) #5: p. 102–123.

39 D. Blochinzev, L. Nordheim, Zur Theorie der anomalen magnetischen und thermoelektrischen Effekte in Metallen, in: Zeitschrift für Physik 84 (1933), p. 168–194. For a detailed review of Blokhintsev's works, see: A. L. Kuzemsky, Works by D. I. Blokhintsev and the development of quantum physics, in: Physics of Particles and Nuclei 39 (2008), p. 137–172, and A. L. Kuzemsky, On the Contribution of D. I. Blokintsev to Quantum Physics, in: Proceedings XIIIth Int. Conf. on Selected Problems of Modern Theoretical Physics. Dubna 2009, p. 24–35.

pursued by a number of Soviet theorists from the 1920s onward that eventually delivered the modern concept of quasiparticles.[40]

In 1936 he became professor at Moscow University with the responsibility to teach the standard quantum mechanics course on a regular basis (by that time a number of major textbooks were already available in Russian translation, as well as some written by Soviet authors, such as Fock and Yakov Frenkel (1894–1952)). A few years later, Blokhintsev started a new line of research directly related to the ensemble interpretation and almost certainly inspired by Mandelstam's 1939 lectures and Nikolsky's 1940 book. His tactical approach was more cautious, however, in that he did not address the general interpretation problem heads on, but investigated separate mathematical and technical questions that were relevant for both quantum statistics and the eventual systematic development of the ensemble interpretation. Some were done in collaboration, possibly as assignments for advanced students in connection with the quantum mechanics course he taught, and the titles of his published papers speak for themselves: "The quantum Gibbs ensemble and its relation to the classical ensemble" (1940, 2 parts); "On the separation of the system into two parts – a classical and a quantum one" (1941); "Atom as seen in the electron microscope" (1947); "The principle of detailed equilibrium and quantum mechanics" (1947); "The relationship between the mathematical formalisms of quantum mechanics with that of classical mechanics" (1948).[41] The importance of these papers for the ensemble interpretation would become obvious when their results appeared in his textbook of 1949.

The war interrupted these studies: during it Blokhinsev worked on acoustical detection of submarines and mines, which resulted in his 1946 book on the acoustics of the moving media. The patriotic upsurge during the war encouraged many scientists, even those lacking proper proletarian backgrounds, to join the Communist Party, of which Blokhinsev became a member in 1943. At the war's end he resumed his academic duties at Moscow University and at the Physical Institute of the Academy of Sciences. At both places he would be collaborating closely with Markov, his classmate since their student years. The divergence of their views on quantum interpretation does not seem to have affected the personal and professional closeness of their relationship, strengthened by the common penchant for discussing the philosophical dimensions of physics.[42] The Cold War, however, would gradually move Blokhintsev to other assignments, at first part-time, and eventually full-time. Starting in 1947, he supervised as the liaison officer one of the four secret laboratories in which German scientists worked on problems relat-

40 For the history of quasiparticles and the collectivist approach in condensed matter, see: Alexei Kojevnikov, Freedom, collectivism, and quasiparticles: Social metaphors in quantum physics, in: Historical Studies in the Physical and Biological Sciences 29 (1999), p. 295–331.

41 All recently reprinted in volume 2 of his Selected Works: D. I. Blokhintsev. Izbrannye Trudy. Moscow 2009, 2 vols.

42 In the course of their parallel careers in physics, Blokhintsev and Markov most of the time worked in the same units or institutions, possibly following one another, until the mid-1960s. See, for example, A. F. Tulinov, O nashikh uchiteliakh, in: Dmitry Ivanovich Blokhintsev: K 100-letiiu so dnia rozhdeniia. Moscow 2008, p. 5–10.

ed to the Soviet atomic bomb, and after the laboratory was reorganized into one staffed by Soviet researchers, became its director in 1950. His main job would be to develop the reactor for the nuclear power station, which was launched officially in 1954, just in time to be proudly presented as the world's first to the international conference in Geneva.[43] In 1956 Blokhintsev was appointed the first director of the international nuclear institute in Dubna, the socialist countries' analog of CERN and the site of the then largest accelerator of elementary particles.

Compared with these academic and administrative burdens, dealing with the intricacies of the quantum interpretation might seem a relatively unimportant task now, but not by the standards of the time. The ideological debates of the late 1940s elevated the status of quantum interpretation to a publicly important field. Had it not been for that political intervention, Blokhintsev's interpretation could have likely remained buried in several separate articles written in the "general tenor" of statistical ensembles, but relatively invisible to the public, just like Mandelstam's analysis in its unpublished state, or Nikolsky's approach because of the author's lack of authority and the subsequent mental illness that interrupted his scientific research. The ideological campaign motivated Blokhintsev to go ahead with the systematic development of the ensemble approach and ensured that his textbook received much attention, without guaranteeing, however, that the reception would be positive (a safer bet would have been simply criticizing idealism, but without proposing anything particularly novel or controversial). The preparation of the second edition of Blohkintsev's textbook on quantum mechanics (the first one appeared in 1944) was likely prompted by the massive postwar expansion of physics instruction at Moscow University and the establishment of its new department in 1948, with the focus on nuclear physics and related subjects.[44] For a Soviet author writing a textbook around 1950, an engagement with philosophy became a pressing, and for someone who was also a member of the communist party, an obligatory political duty. Blokhintsev fulfilled that obligation in 1949.

The two main assumptions of his overall presentation were spelled out upfront in the book's introduction. First, atomism in the microscopic world is a qualitatively non-classical phenomenon. Blokhintsev was reluctant to use the word "particles," because it carried with it too much of the classical baggage and visual imagery, such as trajectory. He switched instead to "microparticles," characterizing them as similar, in some aspects, to waves, but his main point was that notions

43 D. I. Blokhintsev, N.A. Nikolaev, The first atomic power station of the USSR and the prospects of atomic power development, in: Proceedings of the International Conference on the Peaceful Uses of Atomic Energy Held in Geneva, 8 August – 20 August 1955. Vol.3: Power Reactors. New York 1955, p. 35–55; A. V. Zrodnikov, Yu. V. Frolov. D. I. Blokhintsev – pervyi nauchnyi director laboratorii 'V'. in: D. I. Blokhintsev. Izbrannye Trudy. Moscow 2009, 1: p. 466–489.

44 M. I. Panasiuk, E. A. Romanovsky, A. V. Kessenikh, Nachal'nyi etap podgotovki fizikov-iadershchikov v Moskovskom universitete (tridtsatye-piatidesiatye gody), in: V. P. Vizgin (ed), Istoriia sovetskogo atomnogo proekta. Vyp 2. St. Petersburg 2002, p. 491–518, on p. 506. Blokhintsev organized and chaired the teaching unit (kafedra) on nuclear theory, with Markov as his close collaborator.

from classical physics provided only a crude approximation, fundamentally not suitable for describing microscopic phenomena. Second, "quantum mechanics is a statistical theory… but different from classical statistical mechanics…. Unlike statistical mechanics, modern quantum mechanics is not based on a theory of individual processes. It operates right from the start with statistical collectives – ensembles… and studies these ensembles in their relationship with macroscopic measuring devices."[45]

The ensemble interpretation came developed in his book consistently, for the first time, as the framework for the entire body of quantum mechanics. The main changes did not concern the theory's mathematical formalism and applications, but its basic definitions and the explanations of key experimental facts and thought experiments, including the wave function, the indeterminacy relation, measurement, reduction, and the EPR paradox. ψ was defined as a description of a pure ensemble of identically prepared atomic systems, rather than of one individual system. Measuring devices acted on it like "reference systems," or more precisely, like "spectral analyzers": "the process of measurement transforms a pure ensemble into a mixed one… which is, in practice, a spectral resolution of the initial ensemble into components or sub-ensembles… determined by the specific type of measuring instrument."[46]

Picture 2. A dialogue between Blokhinsev and Bohr, with Stalin looming in the background, photographed during Bohr's visit to the Soviet Union in 1961. The site is close to the Dubna institute on the river Volga, at the entrance to the Moscow-Volga canal. The monument to Lenin is above them, with only part of the granite foundation seen. The visible monument to Stalin would be removed from its foundation the following year, in the course of Khrushchev's de-Stalinization campaign. [Courtesy of the Niels Bohr Archive, Copenhagen].

45 D. I. Blokhintsev, Osnovy kvantovoi mekhaniki. Izdanie vtoroe, pererabotannoe. Moscow-Leningrad 1949, on pp. 10–11. The German translation: D. I. Blochinzew, Grundlagen der Quantenmechanik. Berlin 1953.

46 Ibid, p. 76.

"The seemingly paradoxical nature of quantum mechanics only emerges if one attempts to understand its novel laws from the point of view of old classical mechanics," wrote Blokhintsev after explaining the EPR paradox along Mandelstam's lines. Overall, according to him, quantum mechanics demonstrated the restricted nature of classical atomistic concepts and uncovered qualitatively new statistical regularities in the microscopic world, which had been tested experimentally. It thus confirmed an important tenet of dialectical materialism that every particular state of our knowledge about nature is only approximate and relative, while qualitatively new laws and regularities emerge at every fundamentally different level of material existence. Lenin's dictum from *Materialism and Empiriocriticism* that the main criterion of a materialistic epistemology is the assumption that nature and its laws exist objectively, independently of observer, was equally satisfied by quantum mechanics' ensemble interpretation. "Therefore, from the point of view of dialectical materialism, quantum mechanics should be regarded as the most important development of atomism in the 20th century," Blokhintsev happily concluded his textbook.[47]

CONCLUSION

In an article originally published in 1984, Paul Forman described the ideological preferences that affected the public image of quantum mechanics in Weimar Germany. Despite the highly abstract and counterintuitive nature of the new theory, many commentators preferred to label it *Anschaulich* (the word combining the meanings of "visualizable" and "intuitive," depending on the context.) The concept of indivisible quanta acquired, for Weimar physicists, the deeper meaning of fundamental individuality, *Individualität*, of atomic events and their quantum description. They also tended to perceive the probabilistic laws of the new theory as signifying the principled abandonment of strict causality, *Kausalität*. Such cultural values appealed to the predominantly conservative, anti-rationalist intellectual milieu within which the German physicists operated and became written into the prevailing philosophical interpretation of quantum theory.[48]

Comparison with the Soviet case can help interpret the contrasting preferences demonstrated by Soviet physicists and mathematicians and underscore the insightfulness of Forman's analysis of the German situation. Granted, quantum mechanics was primarily a German invention, and Soviet authors dealt with an already existing doctrine and its public presentation, which to some degree narrowed down the choices available to them. But the dominant cultural milieu in which they operated exerted very different pressures upon them, since the Russian

47 Ibid., p. 555.

48 Paul Forman, Kausalität, Anschaulichkeit, and Individualität, or, How Cultural Values Prescribed the Character and the Lessons Ascribed to Quantum Mechanics, reprinted in: Weimar Culture and Quantum Mechanics: Selected Papers by Paul Forman and Contemporary Perspectives on the Forman Thesis. London & Singapore 2011,p. 203–219.

revolutionaries and the German conservative intellectuals had derived from the common tragic experience of World War I some fundamentally opposite political conclusions about science. The ideals of progress, rationality, and scientism, which all took a major hit on their reputation in Germany, as a result of the war loss, only rose to unprecedented cultural authority in Soviet Russia after the war and the revolution, not just among Marxists, but among the educated public in general, especially scientists.

A representative summary of Soviet ideological values with regard to quantum mechanics can be found in a 1934 address "The development of atomistic views in the 20th century" by Abram Ioffe (1880–1960), the chief public spokesman for Soviet physics at the time. Ioffe was speaking to an audience consisting mostly of Marxist philosophers on the occasion of the 25th anniversary of Lenin's *Materialism and Empiriocriticism* and presented an image of his field designed as the common ground for cooperation between them and the physicists. Quantum mechanics occupied the central place in his talk as the most recent and important expression of the ongoing atomistic revolution in science. The specific philosophical lessons that Ioffe chose to emphasize contrasted sharply with those preferred by his colleagues in Germany. According to him, quantum mechanics was *Unanschaulich* (the corresponding Russian term is *nenagliadnyi*, or non-visual, non-pictorial), statistical but not acausal, and most importantly, it signified a fundamental "loss of individuality" for quantum particles.[49] The existing theory was not yet necessarily complete, given its only recent appearance and continuing disagreements among its main contributors, but together with another profound revolution associated with relativity theory, it was confirming the philosophy of dialectical materialism.

It proved easier to accept and justify the *Unanschaulich* character of quantum mechanics within the revolutionary Russian context, than within the German one. Although some Soviet authors – physicists as well as Marxists – regretted the loss of clarity and of familiar intuitive imagery in physics, their viewpoint became classified as retrograde, associated with the values of classical science.[50] The abandonment of the familiar ways of visual representation, including the notion of electron's trajectory, only confirmed, according to Ioffe, the truly revolutionary nature of quantum mechanics: its radically new laws could not be interpreted in traditional categories of the old physics. The label "revolutionary" obviously carried strongly positive political connotations in public discourse, and it certainly helped the new physics achieve a smooth, enthusiastic reception and early recognition in the Soviet Union. Additional support came from dialectical materialism, which inherited from nineteenth-century Romanticism a basic anti-reductionist belief: nature was supposed to be qualitatively different at various levels of its

49 A. F. Ioffe. Razvitie atomisticheskikh vozzrenii v XX v. in: Pod Znamenem Marksizma (1934) # 4: p. 52–68, on p. 60.

50 On the so-called "mechanists" and their philosophical and scientific defeat, see: David Joravsky, Soviet Marxism and Natural Science, 1917–1932. London 1961.

existence, thus the laws at the microscopic level had to be fundamentally different from those in the macroscopic world and classical physics.[51]

On the other hand, dispensing with *Kausalität* as a fundamental value was practically unacceptable to Russian authors at the time, Marxist and non-Marxist alike, the former usually expressing their attachment to the principle of causality in stronger, explicitly ideological terms. When presenting quantum mechanics, Soviet authors used probabilistic methods and formulae without serious reservations, but – unlike their German counterparts – consistently avoided attaching the label "acausal" to the theory. Such simple ideological accommodation worked satisfactorily in most situations, but some authors went further, by turning the glass that was half-empty into one half-full and claiming that the very explanatory, predictive power of quantum mechanics had revealed novel and more profound causal relations in nature. Others who actually moved beyond rhetoric – such as the authors described in this paper – explored the notion of probability more seriously, in mathematics, physics, and philosophy, and concluded that the validity of statistical laws did not necessitate the abandonment of causality as the fundamental principle, and that the former could be used without sacrificing the latter.

This solution, when applied to quantum mechanics in a consistent manner, asked for dispensing with the absolute validity of individuality. The latter option, it appears, was not seriously entertained in the German context. While *Anschaulichkeit* and *Kausalität* generated a heated controversy there, having both noticeable proponents and opponents, doubting *Individualität* seems to have been largely off limits. In the Soviet political and ideological context, on the contrary, individuality lacked the status of a sacred principle, with much higher value ascribed to collectivism. Soviet authors could thus easier abandon the individualistic rhetoric of quantum mechanics and understand its probabilistic laws as referring to statistical collectives, rather than individual particles. Many otherwise troubling paradoxes of the quantum description could be resolved this way, but the price paid included dropping the important claim that quantum mechanics was capable of describing individual events at the atomic level. Whether such a price was worth paying, or not, depended of course on value choices.

Blokhintsev's ensemble interpretation reflected some of these characteristically Soviet dilemmas and preferences, but it also throws light on why the other popular alternative to the Copenhagen interpretation – "hidden variables" – was not discussed as often in the Soviet Union. Blokhintsev confessed in his later autobiographical essay that from the very beginning, he was sceptical about the hidden variables proposal, because it resembled the restoration of the classical way of describing physical processes.[52] In other words, using Paul Forman's analytical

51 See Loren R. Graham, Science, Philosophy, and Human Behavior in the Soviet Union. New York 1987, Ch.2. Further in Ch. 10 Graham also describes the Blokhintsev case.

52 D. I. Blokhintsev, Moi put' v nauke, in: Izbrannye Trudy, vol. 1 (Moscow 2009), p. 18–72, on p. 33. See also, D. I. Blokhintsev, The Philosophy of Quantum Mechanics. Dordrecht 1968 (translation of the collection of articles published in Russian in 1965).

categories from above, the hidden variables proposal defended causality by reinstating the possibility of *Anschaulichkeit*, at least in principle, and thus undermined what Soviet physicists typically saw as the core revolutionary achievement of quantum mechanics. Instead of rehabilitating *Anschaulichkeit*, Blokhinsev preferred to sacrifice *Individualität.*

Soviet debates about quantum interpretation provide important lessons for understanding the intricate relationship between ideology and science in general, and the official Soviet ideology and science in particular. On the one hand, one can no longer take seriously the old "conflict model" from Cold War historiography, as represented, for example, in the following description: "Soviet Marxists were suspicious of quantum theory because the so-called discontinuities, uncertainties, and complementarities introduced by Planck, Heisenberg, and Bohr respectively, appeared to be extremely difficult to reconcile with such guiding principles of dialectical materialism as absolute causality and universal determinism. Attacks on the achievements of science in the West served as automatic parts of a general war against Western culture and its bourgeois impulses."[53] Besides their obvious political bias, such claims fail to take into account that the Soviet ideological discourse insisted on distinguishing between physical theory and its philosophical interpretations: it strongly supported quantum mechanics, while encouraging the critique of its non-Marxist interpretations.

On the other hand, Max Jammer's and Cross' perception that the ensemble interpretation appeared as a result of the official ideological campaign of the late 1940s needs clarification and correction as well. Scattered remarks and ideas in the spirit of the ensemble approach had been expressed much earlier, in various countries and by authors of different political and ideological leanings.[54] Soviet cultural values inspired a group of physicists and mathematicians to take up these ideas and develop them more seriously and consistently during the 1930s and 40s. The official, politically inspired campaign that started later in 1947 played the role of an amplifier: it gave a strong motivation and opportunity to proponents of these ideas to speak up openly and to larger audiences, assigned political importance, if not endorsement, to their views, and drew enough public attention to the ensemble interpretation, so that the latter became widely known in the Soviet Union and abroad as a serious alternative to the dominant Copenhagen position.

The perception of close association with the official ideology initially provided the ensemble interpretation with wider publicity, but undermined its attractiveness and reputation in the later years. At no time, however, did it become the prevailing Soviet view, let alone the official one. Blokhintsev's textbook circulated in many copies and was recommended for university instruction, but so were other textbooks, by Soviet and foreign authors, with views much closer to the Copenhagen interpretation. While many active physicists in the Soviet Union knew of the

53 Alexander Vucinich, Einstein and Soviet Ideology. Stanford 2001, on p. 221.

54 A. A. Pechenkin, Ansamblevye interpretatsii kvantovoi mekhaniki v SShA i SSSR, in: Vestnik Moskovskogo Universiteta. Seriia 7: Filosofiia (2004) # 6: p. 103–121; Jammer, op. cit., Ch. 10.

ensemble interpretation, only a few cared enough about philosophy to express support for it. Fock's minimal rephrasing of Bohr's philosophy in the direction of materialism appeared sufficient to many officials, especially after the mid-1950s, when restoring international scientific cooperation damaged by the Cold War became a more important priority for Soviet science policy than criticizing idealistic interpretations. Plurality of opinions remained in the Soviet Union, and discussants agreed to disagree, but Blokhintsev's argument looked more like a minority challenge to the prevailing attitudes among Soviet scientists, rather than the other way around.[55] The main result of the ten years of ideological discussions about quantum interpretation was that the spectrum of debatable possibilities became richer.

Contact:

Prof. Dr. Alexei Kojevnikov
University of British Columbia
Department of History
1873 East Mall
Vancouver, BC
Canada
V6T1Z1
anikov@mail.ubc.ca

55 See Filosofskie Problemy Sovremennogo Estestvoznaniia. Trudy Vsesoiuznogo soveshchaniia po filosofskim voprosam estestvoznaniia. Moscow 1959, for Fock's keynote presentation "Ob interpretatsii kvantovoi mekhaniki," pp. 212–236 and Blokhintsev's discussion comments, pp. 421–426.