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Dialectical Materialism in the Mirror of Quantum Physics

Sanjay Kumar

ABSTRACT: Most proponents of dialectical materialism claim it to be the most coherent understanding of developments within sciences. Hence, it should concern them that there exist seemingly contradictory dialectical materialist understandings of the accepted theory of micro physics. Among physicists who accept dialectical materialism, there are ones who argue in favour of the standard interpretation of quantum physics, as well as others who oppose it. We discuss arguments of two such physicists, Valdimir Fock and David Bohm. They both give physical arguments against the neo-Kantian and positivist elements of the dominant Copenhagen interpretation of quantum mechanics. While Bohm uses the notion of 'qualitative infinity of nature' against the maximalist form of this interpretation, Fock defends a minimalist form of this interpretation with the argument of the 'relativity to the means of observation'. Similarly, their proposals differ on the key question of the origin of randomness in quantum measurements. Despite having a consistent formalism, there are gaps in the physical understanding of quantum physics, and at least part of their divergent interpretations relates to these gaps. It is argued that the divergent views of Bohm and Fock should not be read polemically. Rather, they together help develop a more comprehensive characterization of dialectical materialism as a worldview in development. Arguments of Bohm and Fock explore and substantiate materialist and dialectical themes in physics. Their divergence shows that dialectical materialism cannot pre-empt science. In fact, as sciences discover new properties of matter, dialectical materialism needs to continually renew its repertory of generalized concepts to grasp these properties.

KEYWORDS Dialectical Materialism, Quantum Physics, David Bohm, V A Fock.

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- *Correspondence:* Sanjay Kumar, St. Stephan College, India.
- e-mail: sanjay.kumar@ststephens.edu
- ORCID:-

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Introduction

Quantum Physics (QP) and its extension in the quantum field theory are among the most successful theories of physics. These explain physical phenomena spanning the widest domain known to us; from the current understanding of elementary particles, to the internal dynamics of stars and the large-scale properties of the universe.

The success of QP is based upon a conceptual framework and an operational algorithm that give correct predictions of experimental results. These however fail to provide a clear picture of the objective properties of matter. Positivist and idealist interpretations make virtue of this lack of clarity to challenge the very notion of the objectivity of matter. Hence, in the dominant Copenhagen interpretation associated with founders of QP like Niels Bohr, Werner Heisenberg, Max Born, Wolfgang Pauli, etc., and accepted by most working physicists, no explicit claims are made about the physical nature of entities producing experimental results. Niels Bohr's widely quoted statement, attributed to him by his assistant Aage Petersen, best captures the neo-Kantian grounds of this interpretation. "When asked whether the algorithm of quantum physics could be considered somehow mirroring an underlying quantum world, Bohr would answer, 'There is no quantum world. There is only an abstract quantum physical description. It is wrong to think that the task of physics is to find out how nature is. Physics concerns what we can say about nature'" (Petersen 1963, 12).

If the objectivity of matter is its most basic character, then it is obvious that dialectical materialism (DM) has to deal with issues raised by quantum physics. We notice a surprising phenomenon in this regard. Among the physicists who put their philosophical orientation within DM, are those who give arguments in favour of the standard interpretation of QP, as well as others who oppose it. Within the Soviet Union prominent physicists like Vladimir Fock, and Moisei Markov argued in favour of Bohr's interpretation from a materialist position, while others like Blokhnitsev argued against it and developed alternatives to it.[1] Outside the Soviet Union, an influential alternative to the standard QP, the de-Broglie-Bohm theory was developed in 1952 by David Bohm, who was banished from the US for his alleged links to the CPUSA during his student days. His book *Causality and Chance in Modern Physics* is a

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[1] Loren R Graham provides a comprehensive account of different positions of Soviet physicists on QM and debates among them till the middle of 1960s, (Graham, Loren R. 1966).

serious reflection on important dialectical categories like chance and necessity, and qualitative infinity of nature (Bohm 1984). Jean-Pierre Vigier who made significant contributions to the deBroglie-Bohm theory was a member of the French Communist Party. On the other hand, L. Rosenfeld, who was an associate of Niels Bohr and was an avowed Marxist, argued hard for latter's Complimentary Principle as a dialectical contradiction and joined polemics against Bohm and Vigier (Rosenfeld 1953).[2]

Such divergent positions have been related to ideological struggles within the Soviet Union (Graham 1966; Cross 1991), or to the 'plurality of Marxisms' in the twentieth century (Freire 2019, 99). We address an entirely different question. Given that arguments for and against QP are raised from within a dialectical materialist perspective, what light do these divergent positions throw on dialectical materialism itself? To arrive at a plausible answer, we engage with arguments of David Bohm and Vladimir Fock, the two physicists who besides their original contributions to quantum physics have written extensively on their philosophical understanding of its unique characteristics.

We argue that both QP and DM are unfinished endeavours. Despite a logically consistent and seemingly complete formalism, there are significant gaps in the physical understanding of QP. While these gaps can be filled only by theoretical and experimental advances in quantum physics, arguments of Bohm and Fock clarify core issues at stake from a dialectical materialist perspective. Some of their observations made decades ago gain added significance in the light of recent developments in the theoretical and empirical practices of QP.

The seemingly contradictory arguments of Bohm and Fock arise from different points of emphases in an open field of investigation. Rather than giving a confusing and contradictory picture of the basic tenets of DM, the divergence in their assessment of QP underlines the open-ended nature of dialectical materialist speculation on any science. This openness is essential for DM to remain valid as an evolving world view.

The first section below gives a brief introduction to some of the salient characteristics of DM that have a direct bearing on discussions on QP. We refer to specific contributions of Bohm and Fock, and discuss how these fit into general considerations of DM, as well as indicate possibilities for new developments in it.

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[2] Anja Skaar Jacobsen (2007) provides details of the context of Rosenfeld's severe attack on Bohm's theory.

The second section presents a short account of the conceptual specificities of the QP. We present physical arguments to show gaps in the standard interpretation of QP. These help explain the context of the positivist interpretations of QP. This section also prepares the ground for an appreciation of the arguments of Bohm and Fock in following sections.

The third section brings together Bohm's reflections on quantum physics and physics in general from his first papers on his alternative theory to QP in 1952 to the late 1950s. Interestingly, there is a shift of emphasis during this period, with the book *Causality and Chance in Modern Physics* published in 1957 showing maturation of a process. The fourth section is based upon writings of Fock, in which he puts forth his approach to QP. His emphasis is on new properties of QP which demarcate it decisively from the classical physics, and which also require a reworking of some of the properties of matter recognized by DM.

The fifth section is a comparative analysis of Fock's and Bohm's arguments. We also highlight some of the recent developments in QP, which elaborate significance of their view points. In the concluding section we bring together arguments from the preceding sections, and highlight how the work of Bohm and Fock on QP underlines the necessity for DM to remain an open ended endeavour.

1. Dialectical Materialism

In the preface to the second edition of Anti-Duhring, written in 1885, Engels describes the text as an 'exposition of the dialectical method and of the communist world outlook championed by Marx and myself.' DM can be best characterized as a method and an outlook. It has emerged from simultaneous considerations of materialism and dialectics, and has many unique features which make it distinct from other positions in the philosophy of science. First is its thoroughgoing materialism that runs counter to any form of dualism. This is evident in Engels' identification of materialism with one of the two possible answers to the 'great basic question of all philosophy', the relation of thinking and being (Engels 1946, 14). The roll of philosophers accordingly is divided in 'two great camps' of idealism and materialism, with diverse strands of the latter asserting the primacy of being over thinking, of matter over human ideas about it, and of the physical over the psychical.

DM interprets Spinoza's dictum of mind as a thinking substance (Spinoza 1961, 170) materialistically, and concludes not only that the brain is the seat of mind, but that "Thought is a ... mode of existence of the body," or that, "in the form of man, *Nature itself* thinks." (Ilyenkov 2008, 32; 34). DM hence stands not only against idealism, but also against dualist and agnostic philosophies which accept matter and consciousness, including conscious ideas about matter, as two kinds of fundamentally different entities without any essential connection. In the case of highly abstract theories of matter like quantum physics, a thoroughgoing materialism implies the rejection of phenomenological interpretations that remain content with mathematical relations between observed phenomenon. Instead, the focus is on developing theoretical explanations based upon properties and relations of material entities, including their relationship with the means of observation.

The rejection of what Engels called metaphysical materialism, and the incorporation of Hegelian dialectics, are the second unique characteristic of DM. The metaphysical mode of thought according to him considers "objects and processes in isolation, apart from their connection with the vast whole, … in repose, not in motion, as constants, not as essentially variables." "Dialectics, on the other hand, comprehends things and their representations, ideas, in their essential connection, concatenation, motion, origin, and ending" (Engels 1947, 13).

An important consequence of the dialectical approach is the conclusion that the form of materialism is a function of the state of human knowledge. In fact, in texts like *Ludwig Feuerbach and the End of Classical German Philosophy* and *The Dialectics of Nature*, Engels relies upon the latest developments in the physical and biological sciences of his time to claim the inadequacy of metaphysical materialism. It's reliance upon fixed and immutable categories, and the failure to incorporate 'development through contradiction,' made it impossible to comprehend the latest scientific developments (Engels 1954, 17).

Lenin's formulation in *Materialism and Empirio-Criticism* is even more emphatic in asserting that the acceptable general properties of matter depend upon the state of scientific knowledge. The 'crisis of modern physics,' that arose from developments in the physics of the internal structure of atoms in the late nineteenth century, and which led to claims like 'matter has disappeared' by followers of Mach, was according Lenin a crisis of the mechanistic materialism. The latter was the dominant form in which matter had been conceived following the success of the Newtonian revolution in physics.

> "'Matter disappears' means that the limit within which we have hitherto known matter disappears and that our knowledge is penetrating deeper. Properties of matter are likewise disappearing which formerly seemed absolute, immutable, and primary (impenetrability, inertia, mass etc.) and which

> are now revealed to be relative and characteristic only of certain states of matter." (Lenin 1977, 241)

With respect to QP, DM starts with the assumption that the properties of matter in the micro domain are likely to be very different from those discovered by the nineteenth century physics. As discussed in sections III and IV, both Fock and Bohm have made proposals for what these properties could be. Even if their proposals are inconsistent with each other, these lie within an established line of thinking in DM.

If dialectics prevents DM from claiming the absolute and final knowledge about the world, then its materialism prevents it from sliding into epistemic relativism and indeterminism. Practically gained knowledge about the world is objective, because it is a function of the objective properties of matter at the level it is probed. The fact that the knowledge of different levels appears so different is due to qualitatively different properties of matter at these levels.

The determination of objectively different properties of matter is the beginning of science. A key dialectical materialist insight is that their differences are best explored through their interconnections. Engels at one point in fact characterises dialectics as the 'science of interconnections' (Engels 1954, 62). The most important interconnection according to DM is contradiction, or equivalently, the unity of opposites. Opposites provide the necessary contexts for each other, so that one does not exist without the other. Rather than indicating any inconsistency, contradictions are sites of active research in sciences.

The contradiction between a dynamical law, applicable to individual entities, and a statistical law that is valid only for aggregates, is one of the prime contradictions of QP. Bohm in particular spends considerable effort in explicating the exact role of dynamical and statistical laws in QP, and in physics in general. Fock focuses on the ineliminable role of the means of observation in determining results of observations, and explains how despite this, the quantum description of matter remains objective. He also addresses the tricky issue of the relationship between the abstract and the real in QP.

Given its intimate connection with the ever deepening and expanding sphere of human practices and knowledge about nature, DM has to consciously remain a theory in development. Physics of the micro-world has two unique features relevant to any understanding of general properties of matter. We do not have any direct access to objects of the micro world, and get to know their properties only through the mediation of macroscopic objects with very different properties. Secondly, our theoretical access to them via concepts of QP occurs at a high level of abstraction without real referents. Both of these conditions present a unique challenge to DM which require developing new ideas about general properties of matter, and conditions under which humans gain objective knowledge. Engaging with the ideas of Bohm and Fock is a useful exercise in this regard. Furthermore, reflections of Bohm and Fock on QP are excellent illustrations of the significance of the dialectical materialist framework for clarifying specific issues related to unresolved problems in any science.

2. The Known Unknowns of Quantum Physics

The 'ascent from abstract to concrete' is the key part of scientific practice according to Marx. It is the only "way in which thought appropriates the concrete, reproduces it as the concrete in the mind." The concrete so comprehended "is the concentration of many determinations. Hence, unity of the diverse" (Marx 1973, 34). In the case of physical sciences, the concrete in thought is the comprehension of matter with diverse objective properties, and multiple causal relations among these properties. QP stumbles at some key points in ascending from its abstract formalism to the concrete. It has an elaborate theoretical structure and computational algorithms which partially explain phenomena of the micro world and correctly predict experimental results. It however flounders in providing a clear picture of the concrete reality of the micro world. From the materialist perspective, the three areas where the standard interpretation of QP fails to provide a clear picture are: (i) the relationship of its abstract concepts to the material reality, (ii) the measurement process, and (iii) the possibility of non-local properties of quantum phenomenon.

Theories of physics generally represent relevant physical quantities directly in terms of real mathematical functions. The magnitudes of these quantities and relationships among them can be directly read from the formalism. This is not the case in QP. The quantum wave function, which corresponds to the state of a micro system, is mathematically not a real, but a complex function existing in an abstract, potentially infinite dimensional vector space, called the Hilbert space. Its abstract nature shows in the fact that it can be expressed in different representations. For particle dynamics in ordinary space, it is used either in position, or in momentum representations, as a function of either position or momentum variables respectively. Wave function representations corresponding to internal properties of particles, for example their spin, are given in terms of matrices.

The wave function of a micro system satisfies Schrodinger's equation. For a system of N number of particles, the wave function in position representation is a function of 3N position coordinates for all particles and is defined on a 3N dimensional configuration space. Schrodinger had initially proposed that the conjugate square of the wave function can be interpreted as a 'weight function' on the configuration space, which for a single charged particle reduces to its charge density distribution in space (Schrodinger 1926, 120). Difficulties arose in extending this physical interpretation to a multi-particle system. He could construct the charge density for a collection of particles through a set of complicated mathematical operations on the wave function. He however, himself describes this laboured interpretation in these words. "If we like paradoxes, we may say that the system (of particles) exists, as it were, simultaneously in all the conditions kinematically imaginable" (ibid.). In the meanwhile, Max Born showed that the charge density of a two-particle system formed according to Schrodinger's recipe did not work for the case of quadrupole radiation (Bacciagaluppi and Valentini 2009, 426). A realist interpretation of the wave function in terms of some known physical property turned out to be untenable.

Max Born's probabilistic interpretation of the wave function, and physical properties entailed by it is found to be consistent with all observations. Born's rules interpret wave function as providing probability distributions for different sets of measurements. This means that the result of a single measurement is interpreted as a random, rather than a fixed and a determined outcome.

In classical physics it is assumed that an ideal measurement reveals a pre-existing value of a physical quantity. This is not true in general in QP. Measurements for a physical quantity in a particular state of a micro system give randomly different results. However, the probability distribution of large number of results can be uniquely identified with the state of the system. If the state before the measurement is taken as an objective reality, and measurement results as what we can know about it, then the two are related not by a determinate one to one relationship, but by a probability distribution. Conversely, if the appellation objective knowledge is attached only to what is uniquely known about an entity, then our objective knowledge about a micro entity is restricted to the probability distribution of a large number of measurement results, rather than the result of a single measurement.

There are special states of the system for which measurement results of a physical quantity are not randomly different but have the same value. These states are called eigenstates of the system for the physical property. For these states the one-to-one relation between the objective reality, and our knowledge of it as revealed in a measurement is valid.

The characterisation of physical properties in QP is a mix of determinate and indeterminate realisations. The mass, charge and the magnitude of the spin angular momentum of elementary particles have completely determined values. If the state of the system happens to be an eigenstate of a physical property, then also its relevant values are unambiguously determined. However, properties of the non-eigenstates have an indefinite, probabilistic character. Quantum objects and processes have a hierarchy of determinations, which is lacking in the case of classical objects where all properties are equally determinate.

In most cases of indeterminacy, like for the throw of a dice, the understanding is that the property has a definite value, but we are unaware of it before the final result shows this value. Hence, we can only guess this value, and the probability distribution of different results represents the lack of complete knowledge on our part. Notably, Einstein was a proponent of this kind of realist but epistemic interpretation of indeterminacy in QP (Leifer 2014, 72).

Since measurement results on the *same* state are randomly different, the quantum state actually does not have the value found in the measurement. Nevertheless, it is possible that states characterised as the same in quantum formalism are actually different. This will happen if there are dynamical variables not included in the quantum formalism, which take different values in states seen as identical in QP. Then one can argue that the seemingly random measurement results are actually determined by these 'hidden variables.'

A realistic interpretation of QP will be based on such hidden variables. However, this is not possible for all dynamical variables, including spin and its functions. Indeed, there are 'no hidden variables theorems'[3]

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[3] The original 'no hidden variable' theorem of von-Neumann derived in 1933 tried to show that a theory with *any* hidden variable is inconsistent with the observed probability calculus of QM. von-Neumann's proof was shown as inconsistent by Grete Herman in 1935 in an article published in a philosophy journal. Bohm's theory developed in 1952, which uses 'hidden variables' and makes the same predictions as the standard QM for particle dynamics, was a practical refutation of von Neumann's theorem. Bohm also gives arguments for the failure of assumptions of von Neumann in his 1952 papers and the book *Causality and Chance* (Bohm 1952a; Bohm 1952b and Bohm 1984 [1957], 65–66). Herman's and Bohm's criticisms received little appreciation, undoubtedly due to the

which prove that the observed probability distributions of measurement results for a certain class of physical quantities are not consistent with the presence of determinate hidden variables (Bell 1966; Kochen and Specker 1967). All instances of indeterminacy in QP cannot be understood realistically as a possible lack of knowledge about otherwise well determined variables.

Inscrutable Measurement and Idealist Fantasies

Unlike in classical physics where a measurement is supposed to passively register a pre-existing value, the interpretation of measurement in quantum physics as an active process cannot be avoided. A system in a non-eigenstate before measurement is found to be in one of the eigenstates after the measurement. This transition is variously called the 'jump', 'collapse' or 'reduction' of the wave function. Such terminology indicates the lack of a clear theoretical and empirical understanding of this process.

Since the physical system does not have the value of the measured property before the measurement, it is as if the measurement process co-creates the value. The role of measurement process in the result of a measurement, and the probabilistic nature of a class of measurements in QP have been seized upon to make maximal idealist claims against objectivity of quantum phenomenon. Hence, according to Pascaul Jordan "... we compel it (electron) *to assume a definite position* ... we ourselves produce results of measurement" (Jammer 1974, 161 [emphasis in the original]). Wigner is even more expansive and develops arguments for including human consciousness as part of measurement. According to him, "It is not possible to formulate the laws of quantum mechanics … without reference to the consciousness. All that quantum mechanics purports to provide are probability connections between subsequent impressions of consciousness" (Wigner 1995, 248).

J S Bell's response to claims like the above is typically sardonic, and is reminiscent of Lenin's statement about the presence of alizarin in coal before humans came to know of it (Lenin 1977, 87).

> Was the wave function of world waiting to jump for thousands of millions of years until a single-celled living creature appeared? Or did it have to wait a

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hegemony of positivism among working physicists. The spell of the von-Neumann's theorem was broken by the work of John Bell, who in 1966 showed that an important assumption behind its proof was wrong (Bell 1966). The latter 'no hidden variable' theorems prove the impossibility of such variables only for a certain class of dynamical variables. These do not disallow *all* hidden variables.

> little longer, for some better qualified system … with a PhD? If the theory is to apply to anything but highly idealised laboratory operations, are we not obliged to admit that more or less 'measurement-like' processes are going on more or less all the time, more of less everywhere? (Bell 1990, 34)

The orthodox interpretation of QP treats the wave function collapse during a measurement process as a black box. It should be noted that unlike the probabilistic results of measurements which are observed, the wave function collapse arises as a problem only within the orthodox interpretation. In the alternate deBroglie-Bohm theory, the measurement process is handled within the formal structure of the theory. The role of measurement process in physically producing measured results is explicitly embedded in the theory.[4] In the many worlds interpretation due to Everett, measurement leads to splitting of the world into different world lines corresponding to different eigenstates, without the wave function collapsing to a particular state (de Witt and Graham 1973). Spontaneous collapse theories postulate wave function collapse as a recurring natural phenomenon, rather than occurring only during a measurement (Ghirardi et al., 1986).

Local Causality in Micro Physics

Local causality is the pointwise transmission of physical influence in space. According to the special theory of relativity the maximum possible speed of any such transmission is a constant of nature, the speed of light in vacuum. The formalism of QP has been extended to be consistent with the formalism of special relativity in the form of quantum field theory. On the other hand, predictions of QP also agree with results of specific experiments conducted to explore the *combined effects* of locality and the existence of deterministic 'hidden variables.' These successes have led to the widespread belief that the physics of the micro domain is local, which is not necessarily true.

The discovery of Bell's inequality which could be empirically tested was the landmark development in the determination of locality properties of quantum phenomenon (Bell 1964). This inequality is a quantitative result that would be obeyed by any theory that unlike QP, *explicitly* followed the locality requirement of relativity through hidden variables. On the other hand, QP violates Bell's inequality. A modified version, better for experimental verification was derived by Clauser et

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[4] Peter Holland (1995, Chapter 8) and Travis Norsen (2017, Chapter 7) provide excellent introductions to the measurement process in deBroglie-Bohm theory.

al. (1969). Experiments by Alain Aspect have confirmed the prediction of QP (Aspect et al., 1982a; Aspect et al., 1982b).

Despite the empirical confirmation of the violation of Bell's inequality, misunderstandings have continued about its implications with regard to locality. Physicists are interpreting this result in three ways (i) violations of Bell's inequalities prove that deterministic 'hidden variable' theories are not possible, (ii) that local 'hidden variable' theories are not possible, or (iii) a much stronger claim that the nature itself is non-local, which indeed is what Bohm's theory makes.

Bell derived his theorem explicitly for hidden variable theories that satisfy locality. The alternative theory developed by Bohm is a non-local hidden variable theory and satisfies empirical observations. So, the first implication is not true. Yet surprisingly, it is perhaps the most commonly accepted, and is even endorsed by physics research institutes like the CERN (Chalmers 2022). Among the second and third possibilities, Bell's own later writings, and careful readings of his arguments by Travis Norsen (2017, chapter 8) and Tim Maudlin (2011, chapter 5) make it clear that according to him it is actually the third one that is implied by experimental results. Bell's own clearest statement and argument appear in a 1990 article *La nuovelle cuisine*, where it is argued that the "ordinary quantum mechanics is not locally causal was pointed out by Einstein, Podolsky and Rosen in 1935" (Bell 2004 (1990), 240).[5]

Travis Norsen has explained the continuing lack of clarity with a very revealing deconstruction of conceptual preferences and selective misunderstandings among physicists (Norsen 2017, 233). The Einstein, Podolsky and Rosen paper (Einstein et al. 1935) is believed to be advocating two parallel claims of local causality and determinism. The verification of violations of Bell's inequality is taken to be providing a choice between jettisoning either determinism in the form of hidden variable theories, or local causality. It is not surprising that most physicists

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[5] The argument starts with perfect correlations between measurement results of far separated observers in an EPR set up. The wave function formalism of quantum mechanics predicts the observations, but does not give an account of how this 'action at a distance' phenomenon arises. A locally deterministic 'hidden-variable' theory can explain perfect correlations. Hence, the local hidden variable theory is inferred from the requirement of local causality. However, this theory also predicts values for *another* set of correlations, which turn out to be different from the prediction of QM. Experiments verify the QM prediction for this other set of correlations. Therefore, any local hidden variable theory is impossible. Since such a theory is the only way to avoid 'action at a distance' of perfect correlations in an EPR set up, nature in the form of these correlations *is* a non-local phenomenon.

choose the latter. This is the least disturbing conclusion which leaves both the special theory of relativity and QP intact in their present forms.

While the QP takes the cover of a vague 'wave-function collapse' to avoid taking a clear stance on the issue of non-locality, in Bohm's theory "the 'spooky action at a distance' is embraced as a fact of life from the outset" (Holland 1995, 462). It hence explains experimental observations as a consequence of the physical properties of micro-objects. Maudlin expresses reactions to the non-locality of this theory, and his own response in these words:

> (I)ronically Bohm's theory, which does away with instantaneous wave collapse as a superluminal *physical* process, has been most severely criticized for postulating superluminal influences. This is the price of clarity. By being explicit about what exists and how things interact Bohm presents a definite object of analysis. … Most other "interpretations" of quantum mechanics glory in vagueness. (Maudlin 2011, 134)

3. From Determinism to Dialectics: David Bohm's Counters to QP

The orthodox interpretation of QP derives its anti-realist arguments from the probability calculus of experimental observations. The indeterministic behaviour of individual micro objects is taken as the failure of *any* form of determinism. Since the randomness and causality are taken as un-connected opposites, the existence of the former is seen as proving the impossibility of the latter. In the dualist conception of the history and evolution of physics, while determinism and causality are taken as the core properties of pre-quantum classical physics, indeterminism is believed to be the defining character of QP.

David Bohm argues that determinism vs indeterminism is a false dichotomy. He considers both the Laplacian determinism based upon Newtonian mechanics and the standard interpretation of QP as two instances of the philosophy of mechanism. The latter according him is the unfounded belief that one type of law can explain all of the natural phenomenon. His line of demarcation is between mechanism and what he denotes as the 'qualitative infinity of nature.'

The following discussion is based largely on Bohm's earlier writings culminating in the book *Causality and Chance in Modern Physics* published in 1957. His later speculations about implications of the 'Wholeness and Implicate Order' for quantum physics (Bohm 1980) will not be discussed.

David Bohm is best known for developing an alternative, deterministic form of quantum physics in which a particle always has a definite position, and its motion is guided by a quantum potential which satisfies

Schrodinger's wave equation (Bohm 1952a; Bohm 1952b). The new theory was elaborated in two papers in 1952.[6] From introductory section of the first paper, it is clear that the chief defect of the standard form of QP according to Bohm is its lack of determinism, specifically its failure to provide "precisely definable dynamical variables determining (as in classical physics) the actual behaviour of each individual system, and not merely its probable behaviour" (Bohm 1952a, 166). Bohr's 'principle of complimentarity' is seen as renouncing the "hitherto successful practice of conceiving individual system as a unified and precisely definable whole, all of whose aspects are, in a manner of speaking, simultaneously and unambiguously accessible to our conceptual gaze" (ibid., 167).

Given such arguments, it won't be wrong to surmise that Bohm's main philosophical motivation behind developing his alternate theory was classical determinism, even though as we shall see, his theory departs from the latter in some crucial aspects. As has been noted by his biographer Oliver Junior Friere, Bohm's philosophical position with regard to physics was changing during the mid-1950s (Freire, Oliver Jr. 2019). This was also the period during which according to Friere he had undertaken a serious study of Hegel's Science of Logic, following a suggestion from a fellow Marxist Brazilian physicist Schonberg to the effect "… that Lenin had suggested all good Communists read the German philosopher" (Freire 2019, 89).

Bohm's 1955 paper, *The General Statistical Problem in Physics and the Theory of Probability*, presents a fundamental shift away from classical determinism as the only form of causality in laws of physics. Instead, determinate law is considered "an abstraction because any mechanical variable is coupled to fluctuating perturbations ... coupled to infinity of parameters" (Bohm and Schutzer 1955, 1032). If determinate laws fail to register the complexity of interconnected nature, so do probabilistic laws. In fact, Bohm's motivation in this paper is to counter the impression that non-probabilistic formulations are impossible for statistical problems in physics, which according to him include statistical mechanics and quantum theory. Even though the concept of emergent property is not used, the emphasis is towards explaining the statistical behaviour as an emergent property of aggregates of events or systems.

Causality and Chance in Modern Physics takes an expansive view of developments in physics and places them among certain long standing philosophical tendencies (Bohm 1984 [1957]). Laplacian mechanism is the extension of the formally deterministic character of Newtonian mechanics to the entire world, from the infinite past to the future. The

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[6] The basics of the theory are the same as the pilot-wave theory developed by deBroglie in 1927. deBroglie had stopped working on his theory due to seemingly irresolvable problems indicated by Pauli. Bohm found the counter to Pauli's objections by following the basic assumptions of the theory to the measurement process.

extension of Newton's laws from an isolated system of bodies, where they can be tested approximately, to the entire universe is according to him a "philosophical point of view about the nature of the world" (ibid., 37).

Determinism in the form of a one-to-one correspondence of the states of the world across time is usually considered the most important of characteristic of Laplacian mechanism. Bohm also highlights its other elements, which from his perspective are equally significant. In the Laplacian picture of the world all of its diversity and complexity can "be reduced completely and perfectly to ... the operation of an absolute and final set of purely quantitative laws determining behaviour of a few kinds of basic entities or variables" (Bohm 1984 [1957], 37). Hence, certain properties like mass, positions, velocities, and forces between atomistic fundamental constituents of matter are elevated as the only real physical properties. "The nature of basic parts is believed to be rigidly fixed and does not grow out of the context in which they are placed, nor does it change as a result of action of other parts" (ibid., 38).

Dialectics of Chance and Necessity

The Laplacian mechanistic philosophy conceives natural law as an internal necessity and leaves nothing to chance. Bohm in contrast starts with necessity and chance as mutually constitutive and exclusive opposites. Semantically the two are opposites. However, in reality the two provide contextual backgrounds and limit each other.

The working of no causal law is free from effects of chance fluctuations which arise from a number of independent causal factors active in the background. So, predictions of these laws, and experimental observations which are interpreted in terms of these laws, always occur within a range of 'errors.' Chance fluctuations on the other hand lead to statistical laws. Causal connections and chance contingencies are two sides of all processes.

> Just as a causal law can arise as a statistical approximation to the average behaviour of a large aggregate of elements undergoing random fluctuations, a law of chance can arise as a statistical approximation to the effects of a large number of causal factors undergoing essentially independent motions. (Bohm 1984 [1957], 110)

According to Bohm, if Laplacian mechanism mutilated the dialectic of causal determinations and chance by treating the deterministic form of natural law as its fundamental and absolute form, the orthodox interpretation of quantum physics does the same by treating the observed probability calculus of microsystems as the fundamental and absolute form of the law of nature. Hence, this "interpretation of the quantum theory represents, in a certain sense, a rather natural continuation of the mechanistic attitude of classical physicists, suitably adjusted to take into account the fact that the most fundamental theory now available is probabilistic in form, and not deterministic" (Bohm 1984 [1957], 82).

Qualitative Infinity of Nature

Mechanism, of either the deterministic or the indeterministic form, is a reductive philosophy which allows only quantitative infinities in nature. Bohm's alternate view of qualitative infinity of nature assumes that nature "may have in it an infinity of actual or potentially significant properties," which become dominant under suitable conditions (Bohm 1984 [1957], 104). Any set of properties and laws is then applicable in a limited context with a certain degree of approximation.

One clear axis of the qualitative infinity of nature is the "levels within levels of smaller and smaller entities which constitute substructure of entities above and to an extent explain their properties" (Bohm 1984 [1957], 106). The structure of macroscopic bodies is a prime example of 'levels within levels,' with the sequence of levels going as: the body, molecules, atoms, electrons and nucleus, sub-nuclear particles, and so on.

The conceptual structure of levels within levels is a favourite of reductionism including mechanism, as it makes it possible to explain properties at a level completely in terms of the substructure. Bohm presents a different picture of the subtle dialectic of substructure and background. The basic qualities and properties of any entity are determined not only by its internal substructure, but also by physical processes around it, which constitute its background. The background of any entity is determined by entities and laws at all levels, hence instead of being unidirectional as demanded by reductionism, determinations flow from all levels.

Internal substructure actually helps the background play a decisive role in determining the mode of being at a given level. This is shown by how the background temperature determines the form of matter in a macroscopic aggregate. As this temperature increases sequential dissociations take place from molecules to atoms to subatomic, and further into nuclear and sub-nuclear particles with very different properties. This is an example of the way the "background enters in a very fundamental way even into the definition of the conditions of existence of new basic kinds of entities" (Bohm 1984 [1957], 107). On the other hand, transition temperatures between these sequential dissociations are determined by the sub-structural properties. Hence, the effect of the background is mediated by the sub-structure.

We end this brief roundup of dialectical materialist elements in Bohm's philosophical reflections on quantum physics with a quick look at his own alternative theory to QP. His theory has been called 'the quantum theory of motion' (Holland 1994, 18). It introduces a novel physical quantity, the quantum potential, and provides a clear picture of the motion of individual particles. With a richer physical content, its predictions are non-statistical and it does not suffer from the absence of physical understandings of crucial points like the orthodox QP. It presents a consistent and realist understanding of measurement process. The micro system and the measurement apparatus are treated by the same theory. There is no 'wave function collapse' from a superposed state to one of the eigen-states. The part of the wave function corresponding to the quantum system evolves deterministically to one of the eigenstates.

Analysis of the measurement process in Bohm's theory shows features which are fundamentally different from the classical physics. Since the measurement process for an observable transforms the wave function to one of its eigen-states, the measurement of an observable is not really a measurement of a physical property belonging to the observed system alone. "Instead, the value of an "observable" measures only an incompletely predictable and controllable potentiality belonging as much to the measuring apparatus as to the observed system itself" (Bohm 1952b, 183 [double quotes in the original]). Hence, the classical ideal of the measurement process as a passive reflection of a pre-existing value of a property, is not realised.

4. Vladimir Fock: Adapting the Materialist Framework to the new Quantum Properties

Vladimir Fock (1898-1974) was arguably the foremost theoretical physicist of the Soviet Union. He made original contributions to quantum physics right from its beginnings in the mid1920s. The Hartree-Fock method and Fock space are two of the common quantum physics concepts.

Fock follows a minimalist form of the Copenhagen interpretation, which accepts the probability interpretation and an irreducible role of the measurement apparatus in empirical observations.[7] Quantum Physics according to Fock is fundamentally different from classical physics to have definite implications for dialectical materialism. Discussion of these appear at number of places in his writings, the most precise perhaps being his 1957 article *On the Interpretation of Quantum Physics* and a 1971 article *Quantum Physics and Philosophical Problems* (Fock 2005 [1957] and Fock 1971). He opposes the idealist and positivist spin given to the new physical notions introduced by quantum physics, and in fact considers many of the latter as "brilliant examples of the application of dialectics to questions of natural sciences" (Fock 2005 [1957],

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[7] As mentioned by Loren Graham (Graham L.R. 1966) this has also been called the 'core meaning' of Copenhagen interpretation by N R Hanson (Hanson, N.R. 1959).

556). He is also emphatic that it is "impossible to get rid of them trying to reduce the story so far to the ideas quotations of the classics are ready for" (ibid., 542). His lesson is clear; dialectical materialism needs to be developed creatively to account for philosophical implications of quantum physics. He is critical of theories proposed by Bohm and Vigier as too close to classical physics and missing the thrust of new ideas. (ibid., 540).

Relativity to the Means of Observation

To appreciate the radically new in QP, it is essential to properly characterise distinctive properties of the classical physics. Fock characterises the classical mode of description of physical properties as *absolute* and *exhaustive* (Fock 1971, 297). By absolute he means that these properties can in principle be understood in themselves, without any reference to conditions or means of observation. All basic properties needed for a complete description can be simultaneously observed and integrated into the relevant theoretical treatment, which makes classical description exhaustive. Both these characters of classical description are abstractions. For example, a reference frame, as a means of observation, is essential to describe the state of motion of a particle. Descriptions of the same motion are different in different reference frames. A freely falling body appears to be on a straight line trajectory in one frame, and on a parabolic one in another. Different descriptions are however related by coordinate transformations between frames of reference, which depend exclusively upon properties of these frames. This leads to the abstract conception of the state of the motion of the particle in-itself, which is described differently in different frames, but is independent of any frame of reference.

This is not the case in QP. "Fundamental physical facts, like the dual, wave-corpuscular nature of light and matter constitute convincing evidence for the assertion that the classical modes of description cannot be applied to micro-objects" (Fock 1971, 297–98). Basic equations $E = \hbar w$ and $\mathbf{p} = \hbar\mathbf{k}$, link indivisible packets (i.e. corpuscular) of energy and momentum to wave properties of frequency and wave number. Hence, both sets of properties belong to the micro-object. However, the two sets of properties are manifested only under specific conditions of observation, which are mutually exclusive. The independence of the phenomenon under observation from means of observation is no longer possible. The "very possibility of observing micro processes (and micro-objects) presupposes the presence of definite physical conditions which may be intimately connected with the phenomenon itself" (ibid., 296). Any theory of micro-objects has to be consistent with the requirement of relativity to the means of observation.

Besides the above general claims, the relativity to the means of observation in QP entails a very precise formulation, which actually provides an objective description of micro-objects in the form of their wave function. The classical mode of description cannot be simply discarded because “an objective description requires as a basis something approximately independent of the way the observation is done, and this is just the absolute mode of description used in classical physics” (Fock 1971, 298). The means of observation must be described on the basis of classical abstractions. This seemingly contradictory requirement, getting an objective description of objects whose properties show up only in relation to means of observation, is realised with the help of the division of any experiment on micro-objects into three stages.

The first stage of any experiment is the preparation of the micro-objects (for example a stream of monochromatic electrons). The second, working part, involves micro-objects interacting with a defined external condition (for example a crystal in a diffraction experiment). The recording of the result of the experiment in the last part is achieved with the help of a ‘device’. A device is a technical construction able to interact with the micro-object on the one side, and present results of this interaction in a classical manner on the other with the required accuracy, and “therefore does not require further observational tools” (Fock 2005 [1957], 532).

The interaction of a micro-object with a device reveals properties like mass, charge, spin, and others described by quantum operators, which are independent of the measuring device. This interaction also reveals other properties related to corpuscular or wavelike character, which are manifested only in external conditions of specific measuring devices.

Abstract Objectivity of Wave Function

Given an initial state of the object, the last registering part can be changed to measure different properties like position, velocity, energy, etc. All of these properties are registered as probability distributions in the final stage. Result of any measurement can be parametrically determined from a single wave function, which does not depend upon the last stage of the experiment. The wave function hence provides an objective description of the state of the object.

The objectivity of the wave function is of an abstract character, different from that of classical theoretical concepts. The state given by the wave function is a state of potential possibilities. It indicates results of interactions in the final stage of the experiment yet to take place, when the transition from the possible to the actually real occurs. These results are not uniquely pre-determined, and can only be stated in a probability distribution. In contrast, the classical physics assumes a unique series of events, which can in principle be predicted with infinite precision. Hence, what is possible also turns out to be the actual, the two are isomorphic. This led to the Laplacian form of determinism, and its extension to all branches of physics, so that “it started to pretend to be the only scientific one" (Fock 2005 [1957], 550). In actual life however, the distinction between potentially possible and its realisation is very real. "Quantum mechanics restores the rights of difference between the potential possibility and its realisation dictated by everyday life."

While probability is an essential element of the description of micro-objects, Fock also leaves a hint regarding its physical origin. "A series of interactions leads to a statistics that corresponds to a definite probability distribution" (Fock 1971, 301). We also read that probabilities in QP "characterise not the behaviour of the particle 'itself' but its influence on the device of a given kind" (Fock 2005 [1957] 551).

Fock's explanation of the so-called 'wavelet reduction,' which occurs in the third stage of the experiment, and whose interpretation has been the chief line of attack on the existing formulation of QP, has a direct significance for his understanding of causality in micro-physics and its implications for dialectical materialism. The wavelet reduction entails change of wave function. It is a change in the domain of probabilities, accounting for the realised result of the measurement, and hence the new wave function. It occurs at once, but does not violate the causal principle of the finite speed of propagation of action, because the wave function is not a real field and "its sudden change is not a physical process like a change of a field" (Fock 2005 [1957], 554). This makes it clear that for Fock the wave function is an objective characterisation of potential possibilities inherent in the state of a micro-object, but itself is not physical. However, he is also careful to clarify that "a physical process is in fact related to an experiment, but it influences the wave function indirectly by means of the requirement to reformulate the question of probabilities."

The general sense of the principle of causality in natural sciences is related to the existence of laws of nature, and spatio-temporal properties like impossibility of affecting the past, and the finite speed of propagation of action. Hence, the time evolution of potential possibilities of a micro-object according to Schrodinger's equation is a law like phenomenon. Unlike Laplacian notion of causality which allows for only unique series of events, the causality in QP includes law dependent changes in potentialities. Phenomenon like the decay of stationary atomic states, and radioactivity are examples of this kind of law.

Since in debates over interpretation of QP, Fock upholds essentials of the Copenhagen interpretation, it is important to underscore his reaction to ideas of Bohr. He considers Bohr's ideas as essential to interpreting QP, in particular the notion that "quantum description of an object should be compatible with the classical description of observation (experimental device)" (Fock 2005 [1957], 541–42). In his opinion however, the overestimation of the role of devices also leads to accusations of 'underestimation of the role of abstraction and of forgetting that it is properties of micro-objects that are under study rather than indications of devices.' Properties like mass, charge, spin, forms of energy operator and laws of interaction are absolutely objective and can be considered in abstraction from observation tools. Bohr's assertion of 'uncontrollable interaction' during measurement is confusing because, according to Fock, a physical interaction is always controllable. His counterposing the principle of complimentarity to causality is also found to be wrong, because he interprets causality only in the deterministic Laplacian sense. However, on the basis of personal conversations Fock claims that Bohr's "position is much closer to the materialistic one than it could seem from his papers on the principal questions of quantum mechanics" (ibid., 542–43).

Fock's insistence on dialectical materialism adapting to new physical notions encountered in QP, should not be interpreted to mean that for him further advances would not modify or contradict QP. Fock's approach towards scientific theories is non-reductive, with no theory branded as the final one, and other theories derived from it. "Each theory, and in particular quantum mechanics, is a particular truth" (Fock 2005 [1957], 555). Particularity of any scientific concept, however is no ground for its rejection.

5. Dialectical Materialist Adventures on the Quantum Terrain

Bohm finds the imprecision and positivist elements in the orthodox interpretation of QP sufficiently serious for him to develop an alternative theory. Fock on the other hand finds quantum physics to be uncovering radically new kinds of properties of matter, and is an advocate of incorporating them in a reformulated dialectical materialism. According to Olivier Jr. Freire, a biographer of David Bohm, such divergent positions "should be of no surprise as when speaking of Marxism in the 20th century it is better to use the plural Marxisms than a singular Marxism" (Freire 2019, 99). We argue that the difference between Bohm and Fock with regard to QP is not a manifestation of plurality. Both appear to be sharing essential elements of DM discussed in section II. Differences between them arise from different points of emphasis, and the differences in the solutions, or hints for solutions, they propose for gaps in the physical understanding of QP.

Search for the Materialist Grounding of Objectivity

Materialism recognises the objectivity of the world. But its primary thesis is the primacy of matter over ideal. So, it is not only the objectivity, but the *kind* of objectivity of the world that is key to dialectical materialist elements in the thinking of Fock and Bohm.

Time and again we find them identifying, or looking for material factors behind observed phenomenon. This is important for the physics of micro-objects, because we come to know their properties only through the mediation of other objects and articulation of abstract theoretical concepts. Human artefacts of theory and experiment are essential aids, they are not ends in themselves. Empiricism and positivism claim to be providing practical and theoretical objectivity. Their objectivity is however deceptive. These two philosophies "wherein the scientist 'spontaneously' reflects his/her own practice" (Althusser 1990, 12) are a poor guide to exploring the properties of matter.

Fock's qualifications of Bohr's contributions discussed in Section IV are revealing in this regard. Even though our knowledge has to factor in the relativity to the tools of observation, readings in instruments are not the object of investigation. Objective properties of matter are the prime concern. Mass, energy, or spin, are all objective properties of micro-objects. Fock also considers abstract entities like the wave function, forms of energy operator and laws of interaction as objective, because of their unambiguous relationship with properties of micro-objects. His analysis of experiments as made up of three stages helps in the identification of the precise site of the origin of probabilities in the interaction between a micro-object and a recording device. The materialist grounding of probabilities prevents their neo-Kantian generalisation as a universal condition of human knowledge.

Bohm rejects the orthodox interpretation despite its proven record in making correct predictions and solving problems, for it fails to provide a consistent and precise picture of the material reality of micro-objects. In his 1955 article on *The General Problem of Statistical Law*, he rejects subjective definitions of probability as lack of knowledge. Even the seemingly objective definition of probability in terms of relative frequencies is found to be insufficiently materialist, because relative frequencies too must arise from definite properties of concerned objects. The relevant question for him is, "From what properties existing before the cards are drawn the approximate predictability of the relative frequency come?" (Bohm and Schutzer 1955, 1013).[8] Interestingly, as discussed above, Fock similarly indicates the origin of probability distributions in the final stage of a quantum experiment to 'a series of

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[8] A similar commitment to the materialist thesis of explaining the observed behaviour in terms of properties of objects is seen in the criticism by Peter Holland (Holland 1995, 464) of the criterion of reality used by Einstein, Podolsky and Rosen in their paper (Einstein et al., 1935). The latter define the existence of an element of physical reality by the following condition. "If, without in any way disturbing a system, we can predict with certainty (i.e. with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity." Holland finds it odd 'that something as fundamental as an 'element of reality" is defined "in terms of a high level concept such as 'measurement' …" "(S)urely the latter should be a function of the former." This example also shows that materialism is not the common philosophy of working scientists, and that positivism has a much wider and deeper influence.

interactions.' Rather than considering probability as completely independent of determinate relationships, or as a referent to a particular state of knowledge, both Bohm and Fock advocate relating it to properties of the objects involved.

Fock can be faulted for not following materialist leads, which he himself provides, to their logical conclusions in at least two instances. He criticises Bohr for taking shelter behind the argument of uncontrolled interaction during measurements, because as he argues, an interaction can always be controlled. In the second instance, while arguing that the instantaneous collapse of the wave function does not violate local causality because it is not a physical field, he also clarifies that a physical process influences the wave function indirectly. Physics of the measurement process, and physical correlates of the wave function collapse in the orthodox interpretation are both examples of gaps in the understanding of QP. Fock however does not characterise these as such, and leaves his comments only as caveats.

Towards Dialectics

Laplacian determinism assumes objectivity of the world, and it is also materialist since it assumes atoms, and forces among them as the basic constitutive elements of the world. However, both Bohm and Fock reject it. Their rejection is fortified by these concepts: (i) the contradictory relationship between chance and necessity, (ii) the notion of potentially possible and relativity to the means of observation, (iii) the significance of abstract entities like wave function, and (iv) non-reductive relationships between properties of matter at different levels of analysis. While both of them more or less accept the framework of these concepts, they reach different conclusions with regard to QP.

The notion of 'potentially possible' is used to distinguish the state of a micro-system from the actually realised final experimental result. In the linear causal model of Laplacian mechanism only one world is possible, the one which exists. Specific entities, properties, and events either exist, or they do not exist. The determinations of potentially possible states do not fall into this binary. We deal with them *quantitatively* through the notion of probability. *Qualitatively*, the states with potential possibilities underline the significance of the context for every physical process, event, or entity, which emerges from the diversity and complexity of interconnections. Bohm in *Causality and Chance* locates the origin of fluctuations in the existence of multiple and independent causal factors, and tries to explain probabilities of QP in terms of subquantal factors. Fock follows Bohr, looks in the opposite direction and emphasises the interaction of the micro-object with a classical device. Jury is still out, and the lack of understanding of details of either proposal shows gaps in our current knowledge.

Analysis of a class of measurements in Bohm's theory shows that results of these measurements do not reveal a pre-existing value, but emerge out of interactions in the measurement process. Hence, like the ordinary QP case discussed by Fock, relativity to the means of observation is also a feature of Bohm's theory, despite it having a very different foundation than the ordinary quantum physics. The relativity to the means of observation can easily slip into a positivist question mark about any knowledge of objects 'in-themselves.' On the other hand, principles of *absolutisation* and *exhaustive* description of classical physics discussed by Fock imply that classical objects exist 'out there', and processes proceed 'in themselves.' The unmediated determinism of Laplacian mechanism lends itself easily to a conception of causality, and then, as Fock puts it, gets to monopolise it. Similarly, the classical nature of objects 'out there', and processes proceeding 'in themselves,' can come to stand in for and monopolise the notion of objectivity. Unless a dialectic of the relativity to the means of observation and objectivity is elaborated as a contradictory unity, the two are conceived as dichotomous.

Fock's deconstruction of quantum experiments lays out a concrete realisation of the dialectic of the relative and the objective as two moments of the process of gaining knowledge about micro-objects. Whereas the wave function provides an *objective* description of the state of the micro-object *before* the last stage of the experiment, one of its possible potentials is realised in *relation* to the specific conditions of the last stage. The moment of relativity in QP cannot be abstracted away and made inconsequential. Hence, in Fock's reading, QP realises this dialectic more fully than the classical physics.

As mentioned in section IV above, Fock credits Bohr for making it clear that instruments of measurement in the last stage of an experiment have to be described classically. The two however, provide very different reasons for this. The dialectic of the relative and the objective implies that the objectivity of micro-objects in quantum experiments is always mediated. This however cannot be the case with the instruments of measurement. Their readings must be unmediated and directly accessible. Hence, their objectivity has to be classical in nature. Bohr's explanation for this phenomenon is different. He relates it to the nature of human communicative discourses. According to his assistant Aage Petersen, Bohr offered a "purely logical argument" in support of the idea that the description of measuring instruments must always be given in ordinary language and in the terminology of classical physics. He implies Bohr as believing that, "(B)y the word experiment we refer to a situation where we can tell others what we have done and what we have learned" (Petersen 1963, 12).

An important feature of QP, especially underlined by Fock is the objective status of abstract entities like the wave function and quantum mechanical operators. Yet these are not materially real. Are these to be conceived as Platonic ideal reals?

The status of abstract entities in sciences falls under the problem of the ideal in materialism. Ilyenkov's original contributions in this area have been mostly applied in humanities, education, and political economy. In an insightful recent article Joost Kircz has done a reverse transfer from humanities to physics of the notion of time as a measure of Ideal change, in the same way as "money is the measure of Ideal value in political economy" (Kircz, J. 2023).

Even though abstract concepts in sciences are theoretical in nature, and stand in opposition to the real concrete, they are objective. They are not "a synonym of the subjectively psychological phenomenon occurring in man's brain only" (Ilynekov 1982 [2017], 20). This for instance is the status of *abstract* labour in the political economy of capitalist societies. Objective abstraction of a phenomenon means "considering a quite particular recurring fact with respect to its own immanent content, … ignoring everything this fact owes to the entire totality of the external influences of the broader sphere of reality in which it exists" (ibid., 71–72). Translating this operation to Fock's understanding of wave function, we notice that the 'fact' of an observation of a micro-object is always relative to the means and conditions of observation. On the other hand, the wave function, as the bearer of the objective properties of a micro-object, is determined prior to the last stage of any experiment, where relativity with respect to means of observation becomes active. Hence, the abstractness of wave function arises from 'ignoring' the latter.

We also read that for Marx the term 'abstract' "is linked with … the dialectical interpretation of the relation of forms of thinking and those of objective reality, with the view of practice (sensual activity involving objects) as a criterion of the truth of abstraction of thought" (Ilynekov 1982 [2017], 21). In the case of physical sciences, abstract entities like the quantum wave function gain truth by virtue of their location in the empirical and theoretical practices of scientists.

Abstract entities also occur in the classical physics, except that their relationship with the concrete real is often different than in QP. No actual planetary orbit is a closed Keplerian ellipse.[9] Nevertheless, both are curves in space and the latter is sufficiently close to actual orbits to be considered a reasonable approximation. The theoretical entities of QP like the wave function, which according to Fock refer to *potentialities* inherent in the given state of a micro-system, reflect this state from a

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[9] Elliptical motion is a solution to the two-body motion under Newton's law of gravity. Actual planetary orbits are not ellipses due to influence of other planets, loss of energy due to tidal forces, and the general relativity effects.

heightened level of abstraction. They lack any real referent that can be considered even approximately close in form. Whether the heightened abstraction in QP is a manifestation of certain unique properties of micro-objects, as Fock would argue, or a mistake which for example Bohm's theory corrects with its realist ontology, is still an open question.

New Avenues of the Theoretical and Empirical Practices in QP

As mentioned earlier, Fock criticises Bohr for using confusing terminology like 'uncontrollable interaction' between a quantum system and classical measuring device, because any interaction can be controlled in principle. Recent developments in theoretical and experimental physics are showing how this interaction can be 'controlled' in certain ways.

The conventional measurement procedure, whose random outcomes are interpreted according to Born's rules, was considered the only possible kind of measurement for long. Apart from other methods, Y. Aharonov, J. Anandan and L. Vaidman in 1993 explained an alternative 'protective measurement' method with two unique features (Aharonov et al. 1993 and Aharanov et al. 1996). The procedure *protects* the state of the system from changing during the measurement, so there is no 'collapse' of the wave function to an eigenstate. And second, the result of the measurement is definite, unlike random outcomes of conventional measurements. A protective measurement yields expectation value of the observable in the given state in a single measurement, unlike its statistical determination from large number of measurements.

Two methods have been proposed for achieving the protective measurement in practice. One method uses a slowly changing adiabatic potential to keep the state fixed during a measurement. The other uses quantum Zeno effect which amounts to slowing down the evolution of a state determined by the Schrodinger equation by rapid measurements. Protective measurements have been realised in laboratory (Rebufello et al. 2021). These amount to an active intervention in a process which is taken simply as given in the orthodox interpretation of QP. Discovery of more such procedures would clarify the physical content of processes loosely identified as the collapse of the wave function in the conventional interpretation of QP.

6. Conclusion: DM in the Mirror of QP

Dialectical materialism claims a dual relationship with sciences. Scientific developments are believed to be the proof of the dialectical materialist characterization of the most general properties of matter. On the other hand, proponents of dialectical materialism also claim it to be the most coherent understanding of developments within sciences, and that the lack of its appreciation sometime leads scientists astray into idealism or positivism. Hence, when dialectical materialist readings of a science arrive at seemingly opposite conclusions, it could be either a moment of polemics (in which each side thinks that the other is wrong), or an example of contextually different interpretations based upon similar ideas.

We have argued that seemingly opposite interpretations of QP by Bohm and Fock need to be understood as dialectical materialist takes on an incomplete science whose physical picture of reality retains many unresolved questions. The ontological status of theoretical entities like the wave function, physics of the measurement process, and the non-local correlations are some of the little understood aspects of QP. A significant part of disagreement between Fock's and Bohm's interpretations of QP arises from efforts to come to terms with these unresolved issues.

The commonly encountered dialectical materialist speculations on natural sciences, for example found in writings of Engels, Lenin, or Bukharin, are interpretations of already known facts and unproblematic theories. Theoretical sections of *Capital* on the other hand show Marx's dialectical materialist insights *in action*, as he grapples with the unresolved problems of political economy. The work of Bohm and Fock discussed above falls in this second category. Bohm's speculation on multiple causal determinations producing both deterministic and statistical laws, Fock's three stage division of experiments in QP to explain how objective knowledge is gained despite an irreducible influence of the means of observation, and his understanding of the objective character of an abstract wave function, are investigations into the known gaps of quantum physics. Their scientific detail and content enrich the repertory of perennial themes of DM like the dialectics of chance and necessity, the relative and the objective, and the abstract and the concrete.

The fact that Bohm and Fock disagree on precise implications of DM for understanding QP, reveals an essential requirement for DM if it is to remain relevant to developments in sciences. The dialectical materialist framework must remain sufficiently broad for such disagreements to flourish. If the nature indeed is qualitatively infinite, as Bohm thinks, or as Lenin famously claims,[10] then it is obvious that further scientific investigations will bring out many unanticipated properties of matter. This means that the notions of the most general properties of matter and the most general laws of development must be sufficiently accommodative, if these are not going to be overhauled by every new fundamental discovery into properties of matter. The incorporation of any new property of matter into the dialectical materialist framework

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[10] "(T)he electron is as *inexhaustible* as the atom, nature is infinite but it infinitely *exists*." (Lenin 1977, 243)

requires forging new relationships among the already understood properties. DM has to remain a system of knowledge in permanent development to fulfill this requirement.

Despite nearly hundred years of active research, quantum physics remains an open science. New applications, experimental techniques, and theoretical investigations into its foundations are still on. This is a consequence of the complexity of microphysical properties which are not easily grasped by the modes of thought and physical intuitions developed to deal with objects humans normally deal with. One of the key insights of dialectical materialism is that these modes of thought and intuitions are not a fixed character of human 'nature,' but evolve with the sphere of human practice as it engages with deeper layers of matter. There is no final form and content of human knowledge. The seemingly contradictory dialectical materialist perspectives of Fock and Bohm on quantum physics are not only a sign of the unfinished character of the latter, but also of dialectical materialism.

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