“QUANTUM PHYSICS AND PHILOSOPHICAL PROBLEMS”; SOME NOTES ON A PAPER BY V. FOCK FORTY YEARS AFTER HIS DEATH

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Abstract
Some observations are presented on the well-known article by Vladimir Fock, "Quantum Physics and Philosophical Problems," published in 1971. In this article, which crowns and summarizes for Western readers a long and complicated reflection on the foundations of quantum mechanics (QM), Fock illustrates his "minimal" interpretation of this theory. By minimal we mean that it only uses concepts related to the operational aspects of the measurement procedures, avoiding any mention to definite quantum onthologies (Bell's *beables*). It is argued that, by taking into account the time reversal invariance of the microscopic processes and introducing the notion of irreversibility in an appropriate manner, Fock's description becomes an anticipation of the "transaction" notion introduced by Cramer a decade later.

1. Introduction
Vladimir Fock (1898-1974) was undoubtedly one of the greatest personalities of Soviet theoretical physics. His technical and conceptual contributions to the theory of general relativity (though he did not like this name!), to both classical and relativistic QM and the quantum field theory (think of the spaces that bear his name) are widely known.
Fock was a protagonist of the construction of QM and its dissemination in the USSR. He participated in the "defence" of this theory and, in particular, of the "Copenhagen interpretation", from the attacks by Soviet ideologues, often playing his card in advance and always successfully. But he was also an acute critic of the contradictions and half-truths of the Bohr school ‘from inside', and he had an important impact on its evolution. It is not possible, in this short note, to retrace the steps of his itinerary and the interested reader is referred to other works [1,2,3,4].
This work focuses on what can undoubtedly be considered the goal of Fock's philosophical reflection on the foundations of QM, with particular reference to the non-relativistic QM. This goal is represented by the article entitled "Quantum Physics and Philosophical Problems," published in Foundations of Physics in 1971 [5]. The article is the English version of papers published in Russian at about the same time [6,7].
In this article, Fock analyses the difference between classical and quantum measurement procedures, and introduces the awe-inspiring concept of "relativity with respect to the means of observation", which we will focus on later on. One must remember that Fock was a supporter of dialectical materialism by conviction, not by chance (as we know from reading his private papers) and the article contains several points of reference to that doctrine[1]. However, even a rather rapid reading of the article clearly demonstrates the substantial immunity to this type of philosophy, apart from the author's strong fascination for the same. The text, in fact, never makes reference to the fundamental aspect of Diamat, that is the supposed dialectical relationship (or "dialectical contradiction") between things or events, for example between the preparation and the detection of a micro-object.

[1] For example, at page 303: “We see once more that even the electron is inexhaustible”. Only two references are listed and the first is “Materialism and Empiriocriticism” by V. Lenin.

It can be assumed that the "dialectical materialism" was, in Fock's mind and most likely that of other Soviet physicists, nothing more than a synonym for "realism", i.e. affirmation of the existence of an objective world beyond the observations. We will come back to the significance of objectivity for Fock later on.
The remainder of this note is organised as follows. In Section 2 we will examine the central concepts of Fock's work, introducing his "relativity with respect to the means of observation". In Section 3 Fock's "relativity" is reviewed focusing on the aspect of time reversal invariance of the microscopic component of the experiment (micro-process or micro-object). When this invariance is made explicit, it allows a reinterpretation of Fock's proposal which does not differ - at least in substance - from the "transactional" proposal presented by Cramer a decade later.

2. The Relativity to the means of observation

Fock assumes a fundamental distinction between *apparatuses of observation / measurement,* which are physical systems described by classical laws, and *micro-objects,* described by quantum laws. At a classical level the choice of the measuring apparatus can affect the observed object, perturbing its physical quantities but, at least in principle, this perturbation is always eliminable by means of definite correction procedures. For example, the trajectory of a falling object can be vertical in a reference system and parabolic in another; it is actually the same process described with different coordinates. In QM this issue is more complex:

> *... the very possibility of observing such micro-processes presupposes the presence of definite physical conditions that may be intimately connected with the nature of the phenomenon itself. The fixation of these physical conditions does not only determine a reference system, but also requires a more detailed physical specification.*

Therefore the physical process should not be considered ‘in itself’, but always in relation to these conditions. We can note that this statement admits a profound implication: the wavefunction of a system is indeed relative to a statistical ensemble which is not a set of *intrinsically* identical micro-objects; it is instead a set of identical preparations (or detections) of the micro-object in a defined experimental setup. The legacy of controversy with D. Blokhintsev is here evident; Blokhintsev had previously supported the exactly opposite point of view, at a distance from operationality.
Both the measurement apparatuses and micro-objects are subject to the uncertainty principle. But the uncertainties of the physical quantities that describe the status of the apparatus are much greater than their minimum values that appear in the Heisenberg inequalities, hence the operation of the measuring apparatus is in fact classical. The language used for the measurements is therefore that of classical physics. It is at this level that Fock's "realism" emerges. Fock does not deny the objective reality of the micro-processes, but states that their characterization is only possible through experimental operations that imply the use of apparatuses, which are also objectively existing physical entities. This characterization is summarized in the wavefunction, which is hence related to the preparation of the micro-object; it remains the same regardless of the choice of the next measurement setup, and it is precisely in this sense that it constitutes an "objective" characteristic of the micro-process.
At this point Fock observes that the "complementary" characteristics of the processes / quantum objects illustrated in detail by Bohr appear

> *... only under different and incompatible conditions, while under attainable conditions they manifest themselves only partially, in a “milder” form (e.g. approximate localization, allowed by the Heisenberg relations in coordinate space and in momentum space).*

> *There is no sense in considering simultaneous manifestations of complementary properties in their sharp form; this is the reason why the notion of "wave-corpuscular dualism" is self-*consistent *and devoid of contradictions.*

Using a more modern language, we can say that the corpuscular behaviour only occurs during the emission or absorption of a micro-object, while the wave-like behaviour occurs during the propagation of the micro-object; this means that the two aspects are never in opposition to each other because they occur at different *moments in time.* The meaning of the passage by Fock however, is different: it is not possible to exactly measure conjugated variables that enter into the same uncertainty inequality. Likewise, it is impossible to conduct experiments where the same micro-object simultaneously interferes with itself (wave-like behaviour) and does not interfere with itself (corpuscle behaviour). Thus a micro-object prepared in a certain way gives rise to different behaviours when, after its preparation, it interacts with different apparatuses. This is the principle of "relativity with respect to the means of observation."
At this point Fock introduces his fundamental distinction between *initial* experiment, *final* experiment and *complete* experiment. The initial experiment includes the preparation of the micro-object, for instance of a beam of electrons of a given energy, and the conditions subsequent to this preparation, for instance, the passage of the beam through a crystal; this fixes the properties of the micro-object that will be explored in a subsequent *final* experiment. In Fock's words, the initial experiment refers to *the future*, the final experiment to *the past.* An important fact of Nature, that Fock mentions explicitly, is that once the initial experiment has been fixed, the final experiment can still be selected in a variety of different ways. The ensemble of an initial experiment and a final experiment *actually performed* is referred to as a complete experiment. It is the result of the complete experiment which should be compared with the theoretical prediction:

> *The problem of the theory is thus to characterize the initial state of a system in such a way that it would be possible to deduce from it the probability distributions for any given type of final experiment. This would give a complete description of the potentialities contained in the initial experiment.*

So Fock interprets the wavefunction "collapse" with the usual image of the passage from potency into act. This transition is not a choice between different pre-existing possibilities, but an actual creation of previously inexistent features. Although Fock never use the term "creation", it should be acknowledged that the concept is surprising for a dialectical materialist.
Fock does not explain the existence of probability distributions for the results of a given final experiment in place of classical Laplacian determinism, and simply states that it "necessarily" derives from relativity to the means of observation. In fact, he postulates the Born rule and we will do the same later on.
A further aspect worthy of note is the following: since the probability distribution of a given final experiment is derivable (at least in principle) by the wavefunction associated with the preparation during the initial experiment[2], it will also depend on the value of the parameters that appear in this wavefunction. Some of these parameters may have nothing to do with positions or motions in space, so the completely new idea of non-spatiotemporal degrees of freedom is introduced. This category includes quantities such as the spin, isospin and strangeness.
Before closing this Section it seems useful to highlight an objection by Selleri [8] to the principle of relativity to the means of observation. Selleri considers a variant of the double-slit experiment in which two semi-transparent detectors are positioned behind the two slits. Each of the two detectors

[2] If we wanted to take the actualisation concept seriously, we would have to view the initial wavefunction as a sort of "archetype".

allows the particle to pass undisturbed with a probability *p*, or is activated - detecting the passage - with probability 1-*p*. The distribution of the impacts on the rear screen will hence be the weighted average of three distributions: one (without interference fringes) relating to events in which the first detector has been activated, one (also without fringes) relating to events in which the other detector has been activated, and finally one (with interference fringes) relating to the passages during which neither of the two detectors were triggered. Therefore, with the same measurement apparatus, comments Selleri, it is possible to have behaviours of the micro-object during its propagation that are particle-like (absence of self-interference) and wave-like (presence of self-interference). This disproves the position of Fock according to whom it is the apparatus that determines the behaviour of the micro-object.
Selleri's position does not, in our opinion, take into account the clear distinction that Fock makes between initial experiment and final experiment. In the setup proposed by Selleri, the final experiment is always the same (the impact of the particle on the rear screen) but we are in presence of three distinct initial experiments. In the first experiment, the particle is prepared in the source and is then passed through the first detector; in the second experiment, the particle is prepared in the source and is then passed through the second detector; in the third experiment, the particle is prepared in the source and then passed through both detectors. So the particle propagates itself as a corpuscle in the first two cases, and as a wave in the third case. These two possibilities never occur simultaneously in the same complete experiment.

3. Fock and Cramer

Let's consider the complete experiment during which a micro-object is prepared in the state associated with the wavefunction Ψ and detected in the final state Φ. The "passage from potency into act" is a metaphor that Fock applies to the process $\Psi \rightarrow \Phi$, but could just as well be applied to the reverse process $\Phi^* \rightarrow \Psi^*$ on the *advanced* conjugated wavefunctions.
In fact, due to the substantial reversibility in time of the micro-processes, this metaphor *must* be applicable in both ways, if it is accepted to apply it in one of them. This means that the detection is the initial event that induces in *the past*, in the presence of appropriate physical conditions (initial experiment by Fock), the preparation of the micro-object in a certain state, by means of a "collapse". The complete experiment of Fock is then described by the ordered pair (Ψ, Φ), and this pair contains all the information related to the history of the micro-object: there is no longer any "quantum randomness". This appears when only one of the two terms of the pair is fixed, and so the other takes on different values with different probabilities. Probabilities which, as expressed by the Born rule, are classical *Kolmogorovian* probabilities.
A final experiment of a given complete experiment can serve as an initial experiment of a second complete experiment; this may give rise to a causal chain (…,Ψ) (Ψ,Φ) (Φ,...) in which the ordinary time-oriented formulation of the principle of causality applies *between* the individual pairs of the chain, but not *within* each pair. To find out more about this aspect, one can consider this sequence as a sequence of pairs ...,u)(u,... where u = Ψ, Φ and so on. Each of these pairs represents a single collapse event which includes both an emission of the advanced wavefunction u* towards the past [u)] and the emission of the delayed wavefunction u towards the future [(u]. The emission of u* represents the closing of the *previous* final experiment, the emission of u represents the opening of the *next* initial experiment.
It is clear that this variation of Fock's conceptual model directly introduces the quantum nonlocality (about which Fock could not have a clear view from his historical horizon), and goes very close to the "transactional interpretation" of QM formulated by Cramer ten years later[3] [9,10,11].

[3] In transactional language, the emission of u* is the result of the collapse of the advanced wavefunction coming from the next final experiment, whilst the emission of u is the result of the collapse of the delayed wavefunction coming from the previous initial experiment.

A complementary reading to the transactional version is also possible: the emission of u* can be seen as the destruction of the u state in some kind of "vacuum” or “void”, while the emission of u can be seen as the creation of u starting from this same "void". It is easy to see that this scheme reproduces the cognitive (or informational) arrow of time. In fact, the "void" can be equated to a subject who perceives qualia u (u* = annihilation of u that "enters into the vacuum") and acts by projecting the content u (emission of u which "exits from the vacuum"). It is therefore reproduced the well-known scheme according to which the past is what is perceived, while the future is that upon which is possible to act. In more physical terms, the past is the time domain from which signals are received; the future is the complementary time domain, to which one can send signals.
One can notice that the "void" thus introduced, overshadowed by the quantum formalism but not explicitly represented by it, is outside both time and space. Its "subjectivity" is therefore of a non-individualized cosmic nature. It is this entity of background the environment of the various pairs u)(u, and the interface or connection between them. We are therefore faced with a non-spatiotemporal interface, from which the temporal (and possibly spatio-temporal) order derives as an emergent property. The vision of the single pair (Ψ,Φ) as a four-dimensional reality that emerges from a diachronic process bidirectional in time, proposed by Cramer and the "hylozoistic" vision in terms of pairs u)(u associated to a void-subject are complementary and compatible. They are related to each other like the vase and the two faces of the famous Gestalt figure.
An important aspect is that the representation of the action of the background (the "void") does not require Hamiltonian operators, because it is in fact a form of *vertical* causality that connects the manifest physical reality with a different, unmanifest and timeless state of that same reality. In the usual quantum formalism, this action is however represented by the projector | u><u |. It transforms the ket | u '> into a new ket proportional to | u>, and acts in a similar way on the bra <u' |; in both cases a representation of the quantum leap u '→ u is given. The initial and final extremes of a transaction hence consist of real quantum leaps, such as the decay of a nucleus or the ionisation of an atom. Fock's reasoning, restricted to measurement apparatuses and procedures, can therefore be generalized in relation to any process enclosed within real quantum leaps. And, vice versa, there is never an entanglement between the base states of the micro-object and those of the apparatus in a measurement process; a conclusion that leads to the elimination of the same premise on which the measurement theory, from Von Neumann onwards, has always been based.
A photon impinging on a photographic plate is localized as a quantum leap, consisting in the reduction of a single molecule of silver halide in the emulsion. The determination of the state occurs at this micro-interaction level, while the rest of the measuring chain is classical: the subsequent photographic process leads to the fixation of the darkening of a single halide granule, the one which the reduced molecule belongs to. The subsequent scan of the plate can do nothing but detect that granule as a separate pre-existing object with pre-existing properties (e.g. darkening).
A major limitation that the interpretation of Fock shares with that of Copenhagen is hence superseded, namely the ambiguity on the nature of the wavefunction collapse and the conditions under which it occurs (measurement processes only?). The reduction process does, in fact, become objective, and identified in real quantum leaps.
The problem of the origin of randomness in QM therefore returns to the problem of the randomness of quantum leaps. However, any solution of this problem would invariably require the definition of an ontology to support the QM formalism, and a deliberately minimalist interpretation such as that proposed by Fock does not take such problems into consideration.
Yet, due to its minimalism, Fock's proposal can be very useful for all those using the theory (especially non-relativistic) in application domains such as molecular physics, solid state, etc. which require a clear and simple metatheoretical reference. They are, in fact, interested to a clear and direct connection with the experiments and, in this respect, Fock's proposal is without doubt excellent.

Conclusions

The relativity with respect to the means of observation therefore remains, in our opinion, a most useful concept for the teaching of QM and for a correct understanding of its physical meaning, at least as far as the non-relativistic domain in concerned. When the advanced propagation of the conjugated wavefunction is taken into account, this approach broadly overlaps the concept of transaction introduced by Cramer later on. We can conclude by stating that this extension of Fock's proposal, which appears to be very natural, leads to an objective view of the wavefunction collapse that removes the classical measurement apparatuses from their privileged position.

References

[1] Omelyanovskij M.E., Fock V.A. et al; The Materialistic Interpretation of Quantum Mechanics – Physics and Philosophy in USSR; S. Tagliagambe ed., Feltrinelli, Milano 1972. (in Italian)

[2] Graham L.R.; Quantum Mechanics and Dialectical Materialism; Slavic Review 25 (3), 381-410 (1966)

[3] Kojevnikov A.; Probability, Marxism and Quantum Ensembles; University of Columbia (preprint)

[4] Gorelik G.; Vladimir Fock: Philosophy of Gravity and Gravity of Philosophy, in “The Attraction of Gravitation: New Studies in the History of General Relativity”; Earman J., Janssen M. and Norton J.D. eds, pp 308-331; Birkhauser, Boston 1993

[5] Fock V.A.; Quantum Physics and Philosophical Problems; Foundations of Physics 1(4), 293-306 (1971)

[6] Fock V.A.; Principle of Relativity to Means of Observation; Vestnik Akademii Nauk SSSR 4, 8-12 (1971) (in Russian)

[7] Fock V.A.; Quantum Physics and Philosophical Problems, in “Fizicheskaya Nauka i Filosoftya”, Omelyanovsky M.E. ed, pp 55-77, Nauka, Moscow 1973 (in Russian)

[8] Selleri F.; Paradoxes and Reality, chapter 4; Laterza, Bari 1987 (in Italian)

[9] Cramer J.G.; Phys. Rev. D 22, 362 (1980)

[10] Cramer J.G.; Rev. Mod. Phys. 58 (3), 647 (1986)

[11] Kastner E.R.; The Transactional Interpretation of Quantum Mechanics – The Reality of Possibility; Cambridge University Press, Cambridge 2013