Quantum non-objectivity from performativity of quantum phenomena

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Abstract
We analyze the logical foundations of quantum mechanics (QM) by stressing non-objectivity of quantum observables, which is a consequence of the absence of logical atoms in QM. We argue that the matter of quantum non-objectivity is that, on the one hand, the formalism of QM constructed as a mathematical theory is self-consistent, but, on the other hand, quantum phenomena as results of experimenters’ performances are not self-consistent. This self-inconsistency is an effect of the language of QM differing greatly from the language of human performances. The former is the language of a mathematical theory that uses some Aristotelian and Russellian assumptions (e.g., the assumption that there are logical atoms). The latter language consists of performative propositions that are self-inconsistent only from the viewpoint of conventional mathematical theory, but they satisfy another logic that is non-Aristotelian. Hence, the representation of quantum reality in linguistic terms may be different: the difference between a mathematical theory and a logic of performative propositions. To solve quantum self-inconsistency, we apply the formalism of non-classical self-referent logics.

Keywords: non-objectivity of quantum observables, logical structure of quantum, self-referent logic, photon existence, coefficient of second order coherence, prequantum classical statistical feld, Physarum polycephalum

1. Introduction

On many occasions, Niels Bohr repeated that quantum mechanics (QM) does not yield a description of objective reality; in particular, the values of quantum observables cannot be assigned before measurement (they are not properties of objects) [1]: ‘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’.

Non-objectivity of quantum observables has tremendous consequences for the physical picture of micro-phenomena. It is not easy (if possible at all) to imagine lawful nature without objective properties of physical systems. Therefore, the idea that non-objectivity implies that at the microlevel the universe is totally lawless is a very common consequence of non-objective thought. Although the interpretation of the quantum universe as a totally lawless universe is very

As is typical of Bohr’s writings, the meaning of this statement is not clear. Did he deny the reality of quantum systems—atoms, electrons, photons? (The discussion in this paper is essentially about the nature of the photon. Here we remark that initially Bohr was critical of Einstein’s idea about quanta of the electromagnetic field. However, after the 1920s, he in fact accepted Einstein’s idea.)
popular\textsuperscript{5}, many experts in quantum foundations, including even ‘quantum orthodoxes’, i.e., those who cannot even imagine going beyond quantum theory, feel dissatisfaction in appealing to the concept of a lawless universe for such a lawful formalism as QM. Unfortunately, the only way to escape lawlessness is to appeal to quantum nonlocality: to claim that quantum observables are objective but that there is action at a distance. At the same time, for the aforementioned reason, i.e., unwillingness to go beyond QM, ‘quantum orthodoxes’ do not like Bohmian mechanics. This situation is definitely self-contradictory.

First of all, we repeat our arguments from [10] supporting the non-objectivity of quantum observables. Theoretically, the origin of non-objectivity was well explained by Bohr, who pointed out that the contribution of a measurement device to the result of measurement is irreducible\textsuperscript{6}. Moreover, recent experiments in quantum contextuality, see [11], can be definitely interpreted as supporting the non-objectivity of quantum observables; in any event, there is not even a trace of nonlocality. Thus, if one is not really addicted to nonlocality, one cannot ignore that non-objectivity is the most fundamental feature of quantum phenomena.

What is the source of non-objectivity? Operationally, as was pointed out by Bohr [1], it is the contribution of a measurement device to the result of measurement. However, such an operational explanation does not imply the logical justification of non-objectivity.

In this paper, we argue that the matter of quantum non-objectivity is that, on the one hand, the formalism of QM constructed as a mathematical theory is self-consistent, but, on the other hand, quantum phenomena as results of experimenters’ performances are not self-consistent. This self-inconsistency is an effect of the language of QM differing greatly from the language of human performances. The former is the language of a mathematical theory that uses some Aristotelian and Russellian assumptions (e.g., the assumption that there are logical atoms). The latter language consists of performative propositions that are self-inconsistent only from the viewpoint of conventional mathematical theory, but they satisfy another logic that is non-Aristotelian. Hence, the representation of quantum reality in linguistic terms may be different: the difference between a mathematical theory and a logic of performative propositions. At the level of mathematical theory, we deal with linguistic terms, satisfying the Aristotelian assumptions. At the level of the logic of experimenters performances, we deal with linguistic terms, not satisfying the Aristotelian assumptions.

Thus, we aim to avoid the ‘quantum inconsistency’ by applying modern tools of symbolic logic for studying intelligent behavior (performances), and we will show that quantum behavior satisfies all the basic properties of performances. Logical tools for studying human behavior were first proposed in 20th-century language philosophy. Notice that in the philosophy of language since Ludwig Wittgenstein [12], John Searle [13], and John Langshaw Austin [14], the ideas of non-objectivity of our everyday reality have actively developed within the so-called paradigm of linguistic solipsism (cf the aforementioned views of Bohr, von Weizsäcker, Brukner, Zeilinger). According to this paradigm, we deal with just linguistic reality if we think or act and cannot go outside language and return to things themselves. Any fact is seeable and understandable if and only it is speakable and can be described in a language [15]. So in any thinking we are limited by our possible speech acts and in any activity by speech interactions. Language is part of our behavior and the way we interact with others, for example by commanding, requesting, pleading, joking, and debating. Philosophers of language distinguish performative propositions by designating and expressing our behavior from informative propositions denoting facts. Although informative propositions are truth-functions of the elementary propositions whose meanings are presented by facts and that therefore always have references in the real world, performative propositions are non-objective in principle: we cannot find out any real references for them. They are self-referent and their meanings are just their utterances [12, 14]. In this paper, we will show that some quantum statements should be considered as performative propositions as well.

Notably, informative propositions are always referential, i.e., their meanings do not depend on contexts and refer directly to facts. For example, it rains or it does not. Therefore, ‘it rains’ is a true-or-false proposition. Simple propositions refer to simple facts (‘it rains’, ‘the wind blows’, etc.). Composite propositions refer to composite facts (‘it is raining now, and the wind blows hard’). So we can always suppose the existence of logical atoms: first, logical atoms as simple propositions to build theories by composition rules and second, logical atoms as simple facts to build models by composition rules. And in mathematical logic, we study relations between theories and models.

Let us consider now the proposition ‘I sell asset X’. Its meaning varies in the contexts of different situations, and therefore, it is a performative proposition. For example, at a loss relative to the price at which assets were purchased, rational investors are likely to sell assets. On the other hand, individual investors (they are usually irrational) prefer to sell assets that have gone up in value relative to their purchase price. Meanings of performative propositions depend on contexts and can change over time. For example, investors in their performative propositions (e.g., forecasts) might be optimistic, whereas at other times, they might be pessimistic. So we cannot find out facts as logical atoms for the proposition ‘I sell asset X’. The point is that with the passage of time, investors can build different families of intensions as the meaning of the phenomenon ‘selling asset X’, which can always be self-inconsistent as a result. Self-reference here means that the proposition ‘I sell asset X’ refers not to facts but to different intensions that always change and that can satisfy self-inconsistency. Hence, self-referentiality simply means that there are no logical atoms for

\textsuperscript{5}Among the most active advertisers of this concept, we can mention, e.g., Anton Zeilinger [4, 5], whose theoretical considerations are supported by incredible experimental research in quantum foundations. He and Caslav Brukner wrote a series of papers [6–8] on irreducible quantum randomness. (We remark that the idea that quantum randomness differs crucially from classical randomness was discussed already by von Neumann [9]).

\textsuperscript{6}It is very common to speak about irreducible quantum randomness [4–9]. However, it is very difficult, if possible at all, to define irreducible randomness in mathematical terms.
both performative propositions and their meanings. In this paper, we will show how self-referentiality can be understood for quantum phenomena and propositions about them.

By emphasizing the role of performative propositions in QM, we cannot avoid a discussion of the role of free will. We will show that in QM the problem of free will is involves in considerations—how quantum performances can be thought of and treated as appropriate performative propositions for which there are no real references because they (as well as performative propositions about human interactions) have a non-objective status.

The logical formalism for studying performative propositions was proposed in [16, 17]. In Physarum Chip Project: Growing Computers From Slime Mould [18], supported by FP7, we are going to implement this formalism among others to build up a programmable amorphous biological computer. In this computer, logic circuits are represented by programmable behaviors of *Physarum polycephalum*. Notice that *Physarum polycephalum* is a one-cell organism that behaves according to different stimuli called attractants and repellents and can be considered the basic model of simple actions that are intelligent in the human sense [19–24]. This biological computer has some of the properties of a quantum computer; in particular, we can perform the double-slit experiment for *Physarum polycephalum* to show that the logical basics of *Physarum* behaviors are the same as the logical basics of quantum behaviors. This means that we face performativity, non-objectivity, and self-referentiality not only in human interactions but also in QM [25] and in the behavior of the simplest biological organisms (see also [26] for quantum-like models of gene expression).

### 2. Self-inconsistency of verification of quantum mechanics: the principles of complementarity and individual–collective duality

Typically, discussions of self-inconsistency of QM are based on the principle of complementarity. We briefly present the clearest analysis of this problem, complementarity and self-inconsistency of QM, presented by C Brukner and A Zelinger [29]. They pointed out that N Bohr [1] emphasized that ‘How far the [quantum] phenomena transcend the scope of classical physical explanation, the account of all evidence must be expressed in classical terms. The argument is simply that by the word “experiment” we refer to a situation where we can tell others what we have done and what we have learned and that, therefore, the account of the experimental arrangement and the result of observation must be expressed in unambiguous language with suitable application of the terminology of classical physics.’ Then they remarked that rigorously speaking a system is nothing other than a construct based on a complete list of propositions together with their truth values. For a quantum system, it can happen that two propositions are mutually exclusive. This is a specific case of quantum complementarity. Therefore, in an attempt to describe quantum phenomena, we are unavoidably put in the following situation. On the one hand, the epistemological structure applied has to be inherited from classical physics: the description of a quantum system has to be represented by the propositions that are used in the description of a classical system with Aristotelian semantics, and, on the other hand, those propositions cannot be assigned to a quantum system simultaneously. Now a natural question arises: How to reconcile these two seemingly inconsistent requirements?

In this paper, we show that the problem of self-inconsistency of QM is even deeper than self-inconsistency implied by the principle of complementarity. The essence of quantum self-inconsistency can be better characterized by the principle of individual–collective duality, which can be observed in the *Physarum* behavior as well. For more details about this logic, see [16, 17]): there are no logical atoms, and something that seems a logical atom (e.g., an individual behavior) is in fact a family of other sets (e.g., a collective behavior; see section 8).

For example, let us define true valuations of QM conventionally, in the manner of Aristotle and Russell:

- (i) The property $E$ is actual (true) in a given state $S$ whenever a test of $E$ on any physical object $x$ in $S$ would show that $E(x)$ is true for every $x$ in the state $S$.
- (ii) The property $E$ is nonactual (false) in a given state $S$ whenever a complementary property $\neg E$ of any physical object $x$ in $S$ would show that $\neg E(x)$ is true for every $x$ in the state $S$.

Objects $x$ are interpreted as individuals (logical atoms). Assume that $x$ means quanta, $E$, $\neg E$ properties, discovered in the double-slit experiment, with the following meanings:

$$E := \text{‘the non-detection of the position of } x \text{ on the first screen in one of the two slits and the detection of the position of } x \text{ on the registration screen corresponding to the momentum representation with the interference picture’};$$

$$\neg E := \text{‘the detection of the position of } x \text{ on the first screen in one of the two slits or the non-detection of the position of } x \text{ on the registration screen corresponding to the momentum representation with the interference picture’}.$$  

According to the double-slit tests, we confront the fact that $E(x)$ and $\neg E(x)$ are true for the same state $S$. Obviously, that is self-inconsistent.

Notice that in our paper, we deal only with first-order logic to show that its non-classical version proposed by us, where there are no logical atoms, is a more applicable basic logical theory for QM. Evidently, some disadvantages of first-order logic and its Aristotelian-Russellian semantics for QM can be avoided in logics of higher orders. For example, the statement that the property $E$ is actual (true) in a state $S$ may assume quantifying on $S$ in an appropriate second-order logic. But it is better to avoid the disadvantages of Aristotelian-Russellian semantics right at the level of first-order logic, which is what we are actually doing. So in classical logic the properties $\neg E(x)$ and $E(x)$ as previously defined cannot be true for the same $S$. Obviously, there are properties describing the double-slit experiment that are not self-inconsistent, such as $E := \text{‘if there is a non-detection of the position of } x \text{ on the first screen in one of the two slits, then there is a detection of the position of } x \text{ on the registration screen corresponding to the momentum representation with the interference picture’};$ $E := \text{‘if there is a detection of the position of } x \text{ on the first screen in one of the two slits, then there is a non-detection of the position of } x \text{ on the registration screen corresponding to the momentum representation with the interference picture’}$. Thus, we face the theoretical impossibility of assigning simultaneously true values to all statements of the form $E(x)$ describing the double-slit experiment because some assignments would be self-inconsistent formally, such as $\neg E(x)$ and $E(x)$, although experimentally we can suppose a verification of both $E(x)$ and $\neg E(x)$ in the same $S$. Our logic proposed in this paper extends these limits to describe more properties for the same state than classical logic can allow.
But we can deny our assumptions that $x$ are logical atoms, i.e., we can assume that $x$ are not exclusive individuals. For instance, we can put forward the following self-referent definition of $x$: $\{x\} = \{a, b\}$, i.e., $x$ is both $a$ and $b$, where $a = (b, (a))$ and $b = (a, (b))$, i.e., $a = (b(a(b(a(b...))))))$ and $b = (a(b(a(b(a(b...))))))$ are two mutually dependent infinite streams. Let $E(a)$ be true, $\neg E(b)$ be false, $E(b)$ be false, and $\neg E(a)$ be false. In this case, $E(x)$ and $\neg E(x)$ are true for the same state $S$ and we cannot logically divide $x$ into $a$ and $b$ because $x$ is a simple object, although it is not an individual. In this paper, we will show how we can deal with these strange non-Aristotelian objects logically.

In our paper, we are limited only by an observational language. Notice that the language of any physical theory consists of two different languages: a theoretical language (formal theory with axioms and inference rules) and an observational language (semantics for the theoretical language). The former language contains theoretical terms, which are understood as expressions that refer to non-observable entities or properties. The latter language contains observational terms (observables).

A logic for observables is constructed in the observational language, and a logic for theoretical entities is constructed in the theoretical language. In the early 20th century, there was a philosophical movement of logicism, and its followers claimed that it is possible to construct a general logic for both observables and theoretical terms. This general logic could be called ‘logical physics’. It is a part of logic, where logical properties of terms and propositions in relation to space, time, motion, causality, etc. are studied [27]. Usually, logical physics has been presented by logical tools for reducing propositions with theoretical entities to propositions with observables. In accordance with this task, theoretical terms are understood as follows: a term $t$ is theoretical if and only if it holds, for all methods $m$ of determining its extension, that $m$ rests upon some axioms of some theory $T$; otherwise, it is observational [28]. For example, in classical mechanics all methods of determining the force acting upon a particle appeal to some axioms of classical mechanics (CM); therefore, force is a theoretical term for CM. The entity of spatial distance does not depend on the Newtonian axioms. Hence, it is an observable of CM. Thus, the reduction procedure, which eliminates theoretical terms of an axiomatic theory by means of observables, is considered a set of semantic rules for interpreting propositions with theoretical terms on propositions with observables.

In the manner proposed by R. Carnap and C-O. Hempel, we can reduce theoretical entities by the following schemata: $c \Rightarrow (h \Rightarrow e)$, where $h$ is a proposition in theoretical terms (hypothesis), $c$ and $e$ are propositions in terms of observables such that $c$ expresses certain observational conditions that are satisfied, and $e$ presents suitable detecting devices, which then have to show observable responses.

It was proved that there are always theoretical terms that cannot be reduced to observational terms by any logical schemata. This circumstance of the existence of irreducible theoretical terms shows the rigorous limits of logical physics and logicism in physical sciences generally. For example, in QM there are first, a formal physical theory formulated in a theoretical language and second, its semantics formulated in an observational language describing quantum experiments. There is also a logical way to reduce theoretical entities to observables. This way is presented by quantum logic (QL). Its logical schemas of reduction are as follows:

$$p, q := \text{‘observable } o \text{ has a value in a Borel set } \Delta$$

and such propositions are represented by closed subspaces of a Hilbert space, $H$. The set of all such subspaces forms an ortholattice, $\mathcal{L}(H)$, with $p \leq q$ defined by ‘$p$ is a subspace of $q$’. The logical operations of ‘and’, ‘or’, and ‘not’ are modeled respectively by the operations of meet (infimum), join (supremum), and orthocomplement on $\mathcal{L}(H)$. The lattice $\mathcal{L}(H)$ is atomistic, complete, and orthomodular (non-distributive).

So as we see, another concept of truth is defined in QL, and this concept is radically different from the classical (Aristotelian-Russelian) concept of truth [30] because the QL schemas of reducing theoretical terms are much different from the classical way of Carnap and Hempel. The main problem of QL is that even in non-classical means of interpreting QM there are irreducible theoretical statements. For example, the QM explanations of the double-slit experiment cannot be directly interpreted in QL. Nevertheless, ‘quantum logics can be interpreted as a pragmatic language of pragmatically decidable assertive formulas, which formalize statements about physical systems that are empirically justified or unjustified in the framework of QM. According to this interpretation, QL formalizes properties of the metalinguistic concept of empirical justification within QM rather than properties of a quantum concept of truth’ [30]; see also Garola et al [31, 32] and Rosinger [33]. Garola’s pragmatic extension of QL allows him to define justifications of theoretical statements that cannot be reduced directly; e.g., within this extension it is possible to justify the QM explanations of the double-slit experiment. We may recall that the irreducibility of theoretic entities can imply even scientific anarchism: ‘Science is an essentially anarchic enterprise: theoretical anarchism is more humanitarian and more likely to encourage progress than its law-and-order alternatives’ [34]. Therefore, the pragmatic approach can explicate many presuppositions of quantum physicists and their way of reasoning as one of the possible ways.

Our approach to QL is different from the conventional QL with propositions defined on members of $\mathcal{L}(H)$ and Garola’s pragmatic extension of this QL. First of all, we would like to follow the pure logicism that has been reanimated by unconventional computing recently. In unconventional computing, we appeal to the following schemata of logical reductions: $I \Rightarrow (h \Rightarrow O)$, where $h$ is a theoretical proposition, $I$ is inputs of an unconventional computer (quantum computer, DNA computer, Physarum polycephalum computer, etc.) and $O$, is outputs is this computer. In these schemata, $h$ is interpreted as a processor of a suitable unconventional computer.

Unconventional computing is not so ambitious as physical theories such as QM. This new approach to
computations completely ignores theoretical entities if they cannot be applied in designing an appropriate unconventional (abstract or real) processor. Hence, it deals just with reducible theoretical terms. In our research, we discovered that the behavioral logic constructed for the observables of *Physarum polycephalum* and parasites of Schistosomatidae (Trematoda: Digenea) can be directly applied in the double-slit experiment with quanta. The basic idea of this behavioral logic is in the individual–collective dualism that there are no logical atoms in behaviors. Notice that logical theories for unconventional computing are always constructed in an observational language. In our opinion, the propagation of photons has some similarities with an intelligent propagation of *Physarum polycephalum* [22], parasites of Schistosomatidae (Trematoda: Digenea) [23], and many other living organisms. Perhaps we can claim, regarding a new version of pantheism and idealism, that the same patterns of intelligent behaviors are observed everywhere—from quanta to one-cell organisms and human beings.

3. Self-inconsistency of verification of theoretical viewpoints regarding the photon

Quantum optics (as a theoretical formalism) is based on the well-defined and self-consistent notion of the photon. To couple the theory with experiments (i.e., to verify theoretical terms, to reduce them to observables), we need an operational definition of a photon that can be coupled with its theoretical definition—as an excitation of a quantum electromagnetic field. Operationally, we can define a photon as a click of a photo-detector (e.g., A Zelinger, A Migdall, S Polyakov, private discussions). The main point of our discussion is that such a notion is not self-consistent in the Aristotelian-Russellian sense (it has no sense in their semantics). Although no one has said anything about self-inconsistency of the photon-click definition, the problem is known (in other terms), and it can be called the problem of the existence of the photon. In other words, it is the problem of verifying our theoretical viewpoints regarding the photon. The basic experiment regarding the ‘existence of the photon’ was performed by Grangier [35, 36]. See [37] for reviews of the current experimental situation; see also [38–41] for related experimental studies.

The ideal experiment can be described as follows. There is a single-photon source, a beam splitter and two detectors in each channel of the splitter. If ‘photons really exist’, i.e., the quantum electromagnetic field cannot be represented as a classical electromagnetic wave continuously propagating in space-time, then only one of two detectors has to click. This click can be identified as the presence of a photon in this concrete detector.

We remark that this experiment is a special realization of the double-slit experiment in ‘the particle context’, i.e., the experiment in which both slits are open but two detectors are at work: one behind each slit. The claim that only one of these detectors clicks (for a single-photon source) was considered by Bohr as justification of the principle of complementarity—in combination with the experiment in which both slits are also open but without the detectors behind the slits. The latter experiment represents wave-like interference behavior. Thus, the Grangier type of experiment regarding the ‘existence of the photon’ is of fundamental value for quantum foundations. We propose a new interpretation of experiments of this type.

We point to the well-accepted experimental fact that one can never expect that the coincidence clicks (i.e., happening simultaneously in both detectors) will never occur. There are always coincidence clicks, and there are many such clicks. Therefore, the decision was made to count not the absolute number of coincidence clicks, but the relative number, which is given by the coefficient of second order coherence $g^{(2)}(0)$: the number of coincidences divided by the product of the numbers of singles (i.e., at each of the detectors). In principle, one is fine with getting that $g^{(2)}(0) < 1$. Such a result was used to reject semiclassical field theories. However, in real experiments $g^{(2)}(0)$ is still relatively large (see sections 7 and 9 for details), and the claim that the photon exists, in the operational sense as the click of a detector, is not justified.

In such a situation, the operational (and hence experimentally verifiable) notion of the photon cannot be considered as self-consistent. Any pair of coincidence clicks for detectors $D_1$ and $D_2$ can be interpreted as two mutually complementary events, $A_1$, the photon in $D_1$, and $A_2$, the photon in $D_2$, happening simultaneously. However, logically $A_1$ is a negation of $A_2$. Thus, at the level of real phenomena, the theoretical term ‘photon’ in QM is not verified; moreover, it is self-inconsistent in observables. In our opinion, a possible explanation is that the observables for the photon notion are subordinated to performative regularities of some behavioral entities. And appropriate propositions in observational terms are not factual, but performative.

Hence, it would be better simply to recognize this fundamental self-inconsistency and irreducibility of some theoretical terms in the observables if we appeal to conventional logic and try to proceed toward development of a new quantum theory that would not be based on the conventional logical tools, including classical QL. The modern development of information and computer science provides such a possibility. However, in the 1920s self-consistency of a mathematical theory in the sense of classical logic was a fundamental requirement. Therefore, the self-consistent mathematical theory was created to describe physical phenomena, even if there is no way to reduce theoretical terms self-consistently. Heuristically, self-consistency can be considered as a sign of objectivity: a quantum event is either firmly true or false. Obviously, then, as Bohr pointed out, this is only objectivity of observed phenomena within verifications of a physical theory, i.e., not ‘real objectivity’, which was discussed in the Introduction. Nevertheless, in this situation heuristically one
wants to have some ‘elements of reality’. In our opinion, the self-consistency of the QM formalism is a main source of the permanent psychological drama in quantum foundations: reflections toward objectivity (in various forms, including nonlocal realism, which is rather popular nowadays).

We can summarize the discussion of this section as follows: Some experiments regarding photon existence and the irreducible deviation of the coefficient of second order coherence from zero have demonstrated that the operational notion of the photon is not self-consistent in the observables. This circumstance suggests that we construct a new mathematical formalism for quantum phenomena, which would be based on a logical system permitting behavioral entities that are performative and self-referent. Use of the current mathematical formalism of QM (which is self-consistent) will permanently induce the illusion of the possibility of objective interpretation of QM.

4. Non-objectivity from the viewpoint of self-inconsistency in observables

Let us consider the measurement of a photon’s polarization. Suppose polarization is the objective property of a photon. Thus, the result of the polarization measurement coincides with this objective property, which was predetermined before measurement. However, the presence of coincidence clicks and the corresponding self-inconsistency of the definition of polarizations up and down for the setting \( \theta \) of the polarization beam splitter puts a statistical constraint on this objectivity. Let us consider representation of the quantum state \( \Psi \) used for measurement by an ensemble of systems, which is denoted by \( \Omega \). For the setting \( \theta \), let us denote the ensemble of systems (a subensemble of \( \Omega \)) producing the coincidence clicks with the symbol \( \Omega_\theta \). Hence, the self-consistent definition of the property of polarization in the direction \( \theta \) is possible only for the subensemble \( \Omega_\theta = \Omega \setminus \Omega_\theta = \{ \omega \in \Omega: \omega \notin \Omega_\theta \} \), the complement of \( \Omega_\theta \). Therefore, the vector of polarization can be objectively (and consistently) defined only for the subensemble \( \Omega = \bigcup_\theta \Omega_\theta \). Of course, for each fixed \( \theta \), the probability of coincidence clicks is very small, \( P(\Omega_\theta) = \epsilon < 1 \). However, the probability of the union \( \bigcup_\theta \Omega_\theta \) can be close to 1. (In complementary terms, although \( P(\Omega_\theta) \approx 1 \), it can happen that the probability \( P(\Omega) = P(\bigcup_\theta \Omega_\theta) \approx 0 \).) Thus, the self-inconsistency of the observability of polarization in the form of the presence of coincidence clicks can restrict the possibility of the objective definition of polarization to a very small subensemble of systems prepared in the state \( \Psi \).

The logical possibility that the ‘objectification subensemble’ \( \bar{\Omega} \) can have approximately zero probability\(^9\) makes the project of objectification of quantum observables questionable. In light of the previous consideration, the appearance of non-objectivity in QM is not so surprising. Hence, if one has doubts regarding quantum non-objectivity, he or she has to find strong reasons for this.

However, in principle, regarding the question of objectification we need not proceed under the aforementioned assumption that elements of \( \bigcup_\theta \Omega_\theta \) form a representative sample (or in complementary terms that the objectification subensemble \( \bar{\Omega} \) is a non-representative sample). To destroy objectification, it is sufficient to use the experimentally justified assumption that the probability of each \( \Omega_\theta \) is sufficiently far from zero: \( P(\Omega_\theta) = \epsilon \), where one can take \( \epsilon \approx 0, 03 \) for sources producing photons on demand; see section 9. In such a situation, we cannot proceed with objective polarization, simply because we do not know whether for the coming trial the result will be self-consistent. We may get a single click in one of the channels, but we also may get coincidence clicks.

We may summarize the results of our analysis of the inter-relation of (non-)objectivity of quantum observables and their self-(in)consistency from the classical viewpoint in the following way: The self-inconsistency of reducing theoretical entities of QM to performative descriptions of quantum observables makes truly impossible the objectification of QM observables. (The procedure of objectification with some probability definitely contradicts the standard views of objective reality.)

5. Self-inconsistency contra elements of reality of Einstein, Podolsky, and Rosen

The Einstein, Podolsky, and Rosen (EPR) argument based on the consideration of elements of reality corresponding to quantum observables measured for some specially prepared states\(^42\) (which are nowadays known as entangled states) is one of the strongest motivations for attempts at the objective interpretation of quantum observables. For example, in his considerations leading to Bell’s inequality, Bell pointed out that there is a strong reason to consider quantum observables as objective, precisely because of the EPR argument\(^43\). The EPR derivation of the possibility of assigning to quantum systems in some states the objective values of two incompatible quantum observables was criticized in\(^45\) from the viewpoint of use of Lüders projection postulate in the case of observables with degenerate spectrum instead of the von Neumann original postulate. Now we are attempting to destroy the EPR argument by using the self-inconsistency argument of performances with respect to observables.

Again, as in section 4, we can decrease the probability of objectification in the EPR experiment by considering families of incompatible quantum observables. However, as was pointed out in the preceding section, for our purposes we need not proceed in such a way. Even for a fixed observable, we cannot predict whether the result of the coming trial will permit objectification. (Here we discuss the quantum optics version of the EPR experiment, in which the projections of...
photon polarization on different axes play the role of the original EPR observables, position and momentum.)

This argument shows that the essence of the objectification problem does not involve the presence of incompatible quantum observables.

Now, in the light of our approach, we can recall Bohr’s reply to the EPR argument [47]. Bohr stressed that even for one fixed setting one is not able to assign the element of reality to the first component of a compound system on the basis of the result of measurement of the second component. Thus, he also pointed out that the problem arose already in the case of a single observable. His conclusion matches ours very well (although Bohr did not pay attention to self-inconsistency of theoretical terms with respect to quantum observables).

6. Free will (performativity) against self-inconsistency

Various ‘technicalities’ (see, e.g., the discussion hereafter) play important roles in quantum experiments. These technicalities are not presented in the mathematical formalism of QM. Therefore, the real outputs of experiments deviate from the theoretical predictions based on straightforward mathematical computations. Taking these technicalities into account is a difficult problem. (In fact, it can be treated as part of the quantum measurement problem.) Nevertheless, we can pay attention to the notion that some basic elements of these technical issues of the design of concrete experiments can be considered self-referent performative propositions. We illustrate this situation by considering quantum optics experiments.

All quantum optics measurements are based fundamentally on the proper choice of discrimination threshold. This is a kind of performance that allows us to understand quantum phenomena. For the purposes of our argument, it is important to remark that the setting of a sufficiently high discrimination threshold is an important part of experiments regarding timing information and of selection of the pulses (the too-weak pulses are not taken into account). We have in the present experiment chosen a rather high threshold, which amount[s] to [giving] priority [to] the stability of the counting rates and the reproducibility of the results, rather than to the global detection efficiencies.’ (We have stressed in bold the important fact that Grangier proceeded with a rather high threshold.) Thus, in terms of our approach, the selection of the discrimination threshold plays a fundamental role in minimizing the self-inconsistency of reduction to quantum observables.

Evidently, the standard interpretation of this choice of discrimination threshold is that this is a noise minimization procedure. However, if one uses the operational definition of a photon as a click of a detector, i.e., if one studies the real quantum phenomena rather than just theorizing, there is a problem of separation of ‘noisy photons’ from ‘real photons’, because both types are just clicks of detectors.

By implementing the discrimination threshold, we insert a subjective element into all quantum optics measurement schemes. This insertion is based on our free will—to minimize self-inconsistency of QM (more concretely, self-inconsistency of the operational definition of a photon as a click of a detector) by appropriate performances. This is a complex psychological play. First the scientists created a self-consistent mathematical representation of quantum phenomena. Then they confronted the problem of coupling of theory with experiments. This is really a shadowy area of QM. One would not find so much material on coupling of theoretical entities of QM with real experiments. Typically, one is completely fine with repeating Bohr’s statement that in some experimental contexts photons exhibit particle features. What is the experimental reality of being a particle for a photon? It seems that this important problem is practically ignored in theoretical studies of quantum foundations. However, experimenters have to solve this problem in everyday life. They do not discuss it in the papers presenting results of experiments, and a majority simply ignore it. However, foundation-thinking experimenters understand the importance of this problem, and each of them solves it for himself or herself; surprisingly, the solution is the same: experimentally, a photon is nothing more than the click of a detector. However, according to our interpretation, experiments (of Grangier’s type) have shown that this operational definition of a photon is not self-consistent within classical QL. Again, according to our interpretation, an experimenter minimizes self-inconsistency with the aid of his free will.

Of course, if one considers free will as just a mental illusion and uses the picture of a totally deterministic universe (see K Svozil [48] for a detailed analysis of such a position; also cf G’t Hooft [49]), nature by itself minimizes self-inconsistency in quantum phenomena. However, our analysis showed that even nature would not be able to beat self-inconsistency completely: it has to respect the statistical constraint based on the presence of the coincidence clicks.

We also point to the use of another subjective element in minimizing self-inconsistency of coupling quantum observables (as elements of the mathematical model of quantum mechanics) with real experiments. This is the selection of the time window for identification of the clicks in the two channels of a beam splitter as coincidence clicks. The coefficient $g^{(2)}(0)$ fundamentally depends on this time window. Here again free will plays an important role. This is a performance type element of QM. The size of the time window is determined subjectively, aiming to reproduce predictions of the QM mathematical model. We remark that the role of proper selection of a time window was discussed in great detail in connection with Bell-type tests, see [45, 50–52]. This is a well-known coincidence time loophole for these tests. In this paper, we point out that the same problem arises not only in experiments with entangled photons but even in single-photon experiments.
In general, without subjective determination of technicalities such as thresholds and time windows, an experimenter is not able to approach even approximately matching the QM theoretical formalism. Notice that these technicalities are not elements of mathematical formalism in QM.

We can summarize the discussion of free will, performativity, and self-(in)consistency of QM as follows: The experimenter’s free will plays a crucial role in the improvement of self-inconsistency of quantum observables. Selections of proper values of various ‘experimental technicalities’ can be interpreted as attempting to lower the self-inconsistency of QM presented in the use of performance-type statements in establishing coupling between theory and experiment. Without doing it intentionally, experimenters construct performatory propositions for which there is another, non-Aristotelian, logic.

7. Experiments in ‘photon existence’

It is well known that photomultipliers and silicon-avalanche photodiodes have low efficiency: an essential part of the ensemble Ω of quantum systems representing some quantum state, say Ψ, disappears without any click. The presence of the ‘no-detection’ event also contributes to the self-inconsistency of theoretical terms regarding quantum physical phenomena. For some setting θ, the two events A1—‘polarization up’ and A2—‘polarization down’—are considered complementary; and the appearance of the third event, A3—‘no detection’—destroys self-consistency in quantum observations, even in the absence of coincidence clicks. Therefore, from the very beginning we have considered the experiments in ‘photon existence’, in terms of estimation of the coefficient of second order coherence; the experiments were done with detectors of low efficiency, simply obscuring the problem of self-(in) consistency of quantum entities due to the presence of coincidence clicks.

We are interested in experiments of the aforementioned type with detectors of very high efficiency, with TES detectors. Theoretically, they have 100% efficiency.

However, the main problem is even not in the inefficiency of the detectors. The main problem is that in reality there are no pure single-photon sources:

‘An ideal single-photon source would be one for which: a single photon can be emitted at any arbitrary time defined by the user (i.e., the source is deterministic, or “on-demand”), the probability of emitting a single photon is 100%, the probability of multiple-photon emission is 0%, subsequent emitted photons are indistinguishable, and the repetition rate is arbitrarily fast (limited only by the temporal duration of the single-photon pulses, perhaps); see [40].

Although in the literature one may read about single-photon sources, this is merely a terminological trick. There is a fundamental limit of ‘single photonity’: if the temperature is higher than zero (Kelvin), then in principle a black body that is always present in the experimental setup can radiate a photon in the prepared mode. In optics such a probability (for room temperature) is very small, but it is, nevertheless, nonzero. For the most part, acquiring a real on-demand source that would produce an appreciable amount of photons is hard. On-demand sources that are readily available suffer from low single-photon purity, with g(2)(0) = 0.07. Some heroic efforts have led to lower g(2)(0), but these sources are too dim, hard to align and keep aligned, etc.

Nowadays, it is quite common to refer to a ‘single-photon source’ as a source such that g(2)(0) < 0.5. Such an approach, namely, use of the coefficient of second order coherence to determine whether a source is of the single-photon type and then, for such sources, to measure the same coefficient to establish the operational notion of a photon is definitely based on a circular argument—this is a consequence of the irreducible self-inconsistency of the quantum theory terms, at least of quantum optics.

We can finally say: One has to be well aware that the expression ‘a single-photon source’ is simply jargon used by experimenters. Unfortunately, this expression was taken too literally by the theoretical part of the quantum community. The use of the coefficient of second order coherence for the operational definition of a single-photon source (although acceptable operationally) is totally unacceptable foundationally. The experimental groups working on problems related to foundations of quantum optics have to make new attempts to create much better approximations of single-photon sources. Finally, clean experiments to estimate the coefficient of second order coherencewith such on-demand sources and TES detectors must be performed. Such experiments are difficult to perform. And one of the psychological problems impeding essential efforts toward such experimental studies is that there is a very common opinion that the question of the ‘existence of the photon’ has already been totally clarified. This is the wrong viewpoint. Only the easiest part of experimental studies has been done, using bad sources and bad detectors, which can be considered only a preparatory stage for future real foundational studies in experimental quantum optics.

8. Non-objectivity from the viewpoint of performativity

Let us recall that Kolmogorov’s main assumption in probability theory is that there exists a set partitioned into disjoint subsets and, respectively, the probability measure defined on the given set is calculated as the addition of appropriate probabilities defined on subsets. However, we have just exemplified in the preceding sections that there are observables where the additivity for probabilities is falsified if we deal with behaviors of quanta, living organisms, etc.

The intuition of objectivity that has been felt by a majority of physicists ever since ancient times was first formulated by Aristotle. According to him, there is ‘hypokeimenon’ as the substratum of any predicates. Hypokeimenon is a family of singular events or singular facts (’atoms’ in the first sense proposed by Democritus). For quantum physicists, hypokeimenon is given by the smallest particles and all the
world is described by predicates in relation to these particles, thus: ‘the quantum has the property A’, ‘the complex B of quanta has the properties A₁, A₂, A₃, ..., which explore the physical phenomena x, y, z, ..., respectively’, etc. According to Kolmogorov, probabilities should be involved in our reasoning only for particles (singular events) or their Boolean compositions. However, the double-slit experiment means that photons cannot be considered the Aristotelian hypokeimenon and there are no singular events at all.

According to Aristotle, hypokeimenon, the ‘first subject’, underlying things a, b, c, ..., presents an objective reality. Every underlying thing possesses unique properties. It means that a, b, c, ... are atoms of our database. There is nothing less than they. Due to properties, we can group atoms within different classes P, Q, R, ... The more general the property of a thing, the more extensive the class to which it belongs by virtue of this property.

Hence, the idea of hypokeimenon, underlying things, allowed Aristotle to build up formal databases as well-founded trees of data (i.e., these trees are finite and without cycles or loops). He started with underlying things as primary descendants of trees in constructing ontological (syllogistic) databases. Note that, according to Aristotle, different sciences have different syllogistic databases because they use different means for obtaining predicates for hypokeimenon. Quantum physics follows this Aristotelian understanding of objectivity and differs from the ancient physics only in different ways of creating predicates for underlying things, which are understood now to be the smallest particles.

Syllogistic trees contain genus–species relations among items. We know that in genus–species relations we can consider a branch (a relation between a genus and a species) as implication, where the top of the branch (genus) is regarded as the consequent of implication and the bottom of the branch (species) as the antecedent of implication. Then, for each node of the genera–species tree, we may define an intensity as all reachable genera (all higher nodes) and an extent as all reachable species (all lower nodes). It is known that the greater the extent, the smaller the intensity and the greater the intensity, the smaller the extent.

Thus, Aristotle invented the first logical database. It is designed in his syllogistics. He suggested using this database as a logical frame for different sciences. Therefore, if we claim that a science is a database constructed on the basis of empirical observations by applying logical inference rules, then we can claim that the history of exact science begun with Aristotle.

Let us assume that such a database is closed under all logical operations. Then, in this database, the following relations take place. Let P be a property. Then there is also a property non-P. Further, let P be more extensive than Q (i.e., an appropriate class P is more extensive than Q). We then obtain the following relations (see figure 1):

- Q and non-P are properties that can be false together, but they cannot be true together in relation to any atom of our database.
- P and non-Q are properties that can be true together, but cannot be false together in relation to any atom of our database.
- P and non-P are properties that cannot be true together and cannot be false together in relation to any atom of our database.
- Q and non-Q are properties that cannot be true together and cannot be false together in relation to any atom of our database.
- If Q is true in relation to some atoms of our database, then P is also true in relation to the same atoms of our database.
- If P is not true in relation to some atoms of our database, then Q is also not true in relation to the same atoms of our database.

Thus, in the Aristotelian database we deal with Boolean algebra due to the assumption of the existence of logical atoms (singular events). Since Aristotle, objectivity has been understood as the possibility of constructing databases when there is a ‘subject’, the underlying things, the family of atoms grouped in classes, so that these classes are closed under all logical operations. In different sciences we choose different properties of atoms, and as a consequence we group atoms differently. Such an intuition of objectivity has held in quantum physics until now.

Notably, classical mechanics (CM) can be readily presented as a semantics for the Aristotelian logic closed over logical superpositions of syllogistic propositions of the following kind: ‘All S are P’, ‘Some S are P’, ‘No S are P’, ‘Some S are not P’. The point is that in CM, first we have Aristotelian atoms or individuals defined as particles, and second, in CM the state of a system S consisting of N particles is defined by giving 3N position coordinates and the 3N momentum coordinates. Hence, according to CM, any state of S is fully determined by three values for position and three values for momentum of all particles of S. These two circumstances allow us to define a verification of syllogistic propositions as follows:

SaP: ‘All particles of S with positions S have momentums P’ means that the system S is not empty (i.e., it contains some particles) and for all particles of S, if we know their position S, then we know their momentum P.

SiP: ‘Some particles of S with positions S have momentums P’ means that for some particles of the system S
All other propositions of Aristotelian logic are de

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Figure 2. The unconventional square of oppositions.

we know their position $S$ and we know their

SeP: ‘No particles of $S$ with positions $S$ have

SoP: ‘Some particles of $S$ with positions $S$ do not have

Formally:

$$SaP := (∃A(AeS) ∧ ∀A(AeS ⇒ AeP)); \quad (1)$$

$$SiP := ∃A(AeS ∧ AeP); \quad (2)$$

$$SeP := ¬(SiP); \quad (3)$$

$$SoP := ¬(SaP). \quad (4)$$

All other propositions of Aristotelian logic are defined thus: (i) each syllogistic proposition defined in (1)–(4) is a proposition, (ii) if $X, Y$ are propositions, then $¬X, ¬Y$, $X * Y$, where $* ∈ \{ ∨, ∧, ⇒ \}$, are propositions too. Now the Aristotelian logic can describe properties of our knowledge of systems $S$ of CM.

Nevertheless, we can assume reality without objectivity, i.e., without atoms of databases. In modern logic, universes in which there are no atoms are studied as well. However, in modern sciences the intuition that logical atoms exist has been used up to now, and Aristotle’s reasoning has been intuitively applied.

Notice that any context-based reasoning can be realized only in a universe without atoms. For instance, let us consider the following two propositions from the Bible: ‘bestow that money for sheep’ and ‘bestow that money for whatsoever thy soul desireth’ (Deut. 14:26). Syntactically, if we assume the existence of logical atoms, ‘bestow that money for whatsoever thy soul desireth’ is a universal affirmative proposition ($SaP$) and ‘bestow that money for sheep’ is a particular affirmative proposition ($SiP$); i.e., the first is more general than the second. However, for example, I do not desire sheep and I do not know people who desire them. Perhaps such people exist, but I do not know. Then we cannot plot the classical square (figure 1) because ‘bestow that money for sheep’ is not included in ‘bestow that money for whatsoever thy soul desireth’; e.g., maybe my soul does not desire sheep but does desire many other things. The fact of the matter is that ‘thy soul desireth’ is a performative proposition and it has different meanings in different situations (there are no atoms for that proposition). This means that in this Biblical example the implication $SaP ⇒ SiP$ is false in the general case. Thus, we can assume another semantics, where $SaP$ and $SiP$ are different viewpoints of the same level. Therefore, in the same situation of utterance both statements (‘bestow that money for whatsoever thy soul desireth’, $SaP$, and ‘bestow that money for sheep’, $SiP$) may be simultaneously false but cannot be simultaneously true. In this way we obtain the unconventional square of opposition (figure 2).

The same situation occurs for photons and other quanta. The logical square of figure 1 does not hold for them because logical atoms do not exist for all situations (for the double-slit experiment when both slits are open). Let us consider the propositions ‘the photon can be detected passing through all slits’ ($SaP$), ‘the photon cannot be detected passing through the slits’ ($SeP$), ‘the photon can be detected passing through some slits (probably through the one slit)’ ($SiP$), ‘the photon cannot be detected passing through some slits (probably through the one slit)’ ($SoP$). If it is possible to say that the following implication is valid: if ‘the photon can be detected passing through all slits’, then ‘the photon can be detected passing through some slits (probably through the one slit)’? In other words, if the photon is a wave and is described in a proposition in theoretical terms of ‘wave’, then the same photon is a particle and is described in another proposition in theoretical terms of ‘particle’? Rather there should be the disjunction $SaP$ or $SiP$, but not implication. Indeed, if $SaP$ is true, then the photon is not a particle as commonly understood, and if $SiP$ is true, then perhaps the photon is a particle as commonly understood.

In QM, it is impossible to define logical atoms. Indeed, if there were logical atoms in QM, our propositions would not be performative and would not depend on the context of quantum experiments. It means that reality exists, but it does not correspond to the Aristotelian intuition of objectivity when the underlying things exist, i.e., any behavior is reduced to an individual behavior. Instead of this intuition, we can propose another intuition, non-well-funded objectivity [25], where there are no logical atoms, i.e., there is no ‘first subject’ in the Aristotelian sense. We can add that in our picture of the world there are no things themselves (’Dinge an sich’ in the Kantian sense), nothing, only behavioral complexes described by self-referent performative propositions. It is a kind of idealism proposed in the linguistic solipsism of Wittgenstein and accepted by us. A similar idealistic approach was proposed by E. Husserl. He states that phenomena are nothing more than our consciousness, and pure phenomenology is the science of pure consciousness: ‘Natural objects, for example, must be experienced before any theorizing about them can occur. Experiencing is consciousness that intuits something and values it to be actual; experiencing is intrinsically characterized as consciousness of the natural object in question.
and of it as the original: there is consciousness of the original as being there “in person” [46]. Thus, “the concept “phenomenon” carries over, furthermore, to the changing modes of being conscious of something—for example, the clear and the obscure, evident and blind modes in which one and the same relation or connection, one and the same state of affairs, one and the same logical coherency, etc., can be given to consciousness” [46]. Notice that Gestalt psychology is based on these ideas of Husserl.

Thus, in non-well-founded objectivity there are no logical atoms. What does it mean? We have properties (classes) \( P, Q, R, \ldots \) Some of these classes have non-empty intersections, and some others do not. Logical atoms are classes that cannot be intersected at all; they are singletons. Their intersection is always empty. This fact can be considered the definition of logical atom. Their logical combination (disjunction, conjunction, complement) gives any class \( P \). Notice that Gestalt psychology is based on these ideas of Husserl.

In the double-slit experiment with photons:

- The photon can be detected in all slits \((SaP)\), ‘the photon can be detected in no slits’ \((SeP)\), ‘the photon can be detected in some slits (in QM, it means, just in one)’ \((SiP)\), ‘the photon cannot be detected in some slits (just in one)’ \((SoP)\).

Formally:

(i) \( SaP \) and \( SiP \) are properties that can be unjustified together, but they cannot be justified together in relation to any performative situation of our database.

(ii) \( SeP \) and \( SaP \) are properties that can be justified together, but cannot be unjustified together in relation to any performative situation of our database.

(iii) \( SaP \) and \( SoP \) are properties that cannot be justified together and cannot be unjustified together in relation to any performative situation of our database.

(iv) \( SeP \) and \( SiP \) are properties that cannot be justified together and cannot be unjustified together in relation to any performative situation of our database.

(v) if \( SaP \) \((SiP)\) is justified in relation to some performative situations of our database, then also \( SeP \) \((SoP)\) is justified in relation to the same situations of our database\(^{11}\).

\(^{11}\) We should remark that in logic, implication does not mean a causal relation or deep semantic relationship between antecedent and consequent. For example, the sentence \( 2 + 2 = 4 \) implies that ‘We were born in the USSR’, because both sentences are true. In the case of syllogistic propositions, we group quantified propositions into some classes according to their truth conditions. So this relationship between antecedent and consequent just formally follows from our formal definitions of \( SaP \), \( SeP \), \( SiP \), \( SoP \); see (5)–(8) and their interpretations of quantum observables hereafter. In an informal interpretation, this relationship between antecedent and consequent means that the class of events of non-detection in both slits is the largest. The class of detection in one slit or in both slits is the smallest. This follows directly from our formal definitions hereafter.

(vi) if \( SeP \) \((SoP)\) is not justified in relation to some performative situations of our database, then also \( SaP \) \((SiP)\) is not justified in relation to the same situations of our database.

Notice that in our version of QL, performative propositions expressing observables are not true or false in the conventional sense of Russellian-Tarskian semantics, but they are justified or unjustified. Actually, they have a pragmatic rather than a semantic interpretation. In Austin semantics (also called situation semantics), they are evaluated as successful or unsuccessful in the given situation of utterances. We use some of its versions in our logic of self-referent performative propositions.

So instead of atoms in the quantum universe, we deal with performative situations, i.e., with different intersections of classes (properties) in a collective behavior. The logical theory of performative propositions was proposed in [16, 17].

In this theory we obtain non-well-founded syllogistic trees for which there cannot be underlying things (hypokeimenon). Thus, there is no objectivity in the classical sense. Indeed, we can always define intersections \( A \& B \) for some situations \( A \) and \( B \) such that \( A \& B \) is an infimum of \( A \) and \( B \). Therefore, no atoms can be used for building trees molecules as their superpositions. Instead of underlying things, we suppose situations that can always be intersected.

The Aristotelian logic with syllogistic propositions defined in (1)–(4) is self-inconsistent with respect to quantum observables, although CM plays the role of semantics for this logic, as we have said. Nevertheless, we can offer a non-Aristotelian system without logical atoms, where syllogistic propositions have the following meanings:

**SaP**: ‘All quanta of \( S \) with positions \( S \) have momentums \( P \)’ means that the system \( S \) is not empty (i.e., it contains some quanta) and for all experiments with quanta of \( S \) their position \( S \) is absolutely uncertain for all possibilities and we know their momentum \( P \); in the double-slit experiment: the system \( S \) is not empty and for all experiments with quanta of \( S \) these quanta pass through both slits \((S)\) and their momentum has an interference picture \((P)\).

**SiP**: ‘Some quanta of \( S \) with positions \( S \) have momentums \( P \)’ means that for all quanta of the system \( S \) we know their position \( S \) and we do not know their momentum \( P \); in the double-slit experiment: for all experiments with quanta of \( S \) these quanta pass through one slit \((S)\) and their momentum does not have an interference picture \((P)\).

**SeP**: ‘No quanta of \( S \) with positions \( S \) have momentums \( P \)’ is justified iff ‘Some quanta of \( S \) with positions \( S \) have momentums \( P \)’ is not justified.

**SoP**: ‘Some quanta of \( S \) with positions \( S \) do not have momentums \( P \)’ is justified iff ‘All quanta of \( S \) with positions \( S \) have momentums \( P \)’ is not justified.

Formally:

\[
SaP := (\exists A(As) \land \forall A(As \land AeP)); \quad (5)
\]
All other propositions of non-Aristotelian quantum logic are defined as follows: (i) each syllogistic proposition defined in (5)–(8) is a proposition; (ii) if $X$, $Y$ are propositions, then $\neg X$, $\neg Y$, $X \star Y$, where $\star \in \{\lor, \land, \Rightarrow\}$, are propositions also. This non-Aristotelian logic is a simple version of QL without logical atoms. All its propositions are performative and depend on contexts.

Hence, we can claim: From the viewpoint of performativity and logical theories studying performative propositions, there is no objective reality in the classical (Aristotelian) sense. In QM, scientists try to appeal to objective reality with logical atoms of quantum systems, which causes self-inconsistencies. Therefore, the only outcome is in appealing to non-well-founded reality [25] and performative propositions in QM. Self-inconsistency occurs only in cases of applying classical logic and classical semantics. In our logic, there are no contradictions. The same situation is in the so-called paraconsistent logics, where there are contradictions as new truth values. Self-inconsistency exists only in that we avoid logical atoms, and even contrary statements in classical logic may have non-empty intersections in our new semantics. Thus, the term self-inconsistency concerns only logical properties of our version of QL and not things themselves.

According to Kant, we know nothing about things themselves.

9. Existence of the photon from the viewpoint of heralded photons

Due to applications of ideas of performativity in QM to the problems of a single-photon on-demand source (low coefficient of second order coherence, high brightness, experimental feasibility, etc.), it is possible to propose a workable solution consisting of heralded photon sources, i.e., sources based on parametric down-conversion. These sources produce low levels of classical light in each of the two conjugated modes but have a property that photons are created in pairs: one per conjugated mode; therefore, detecting one photon in one mode means that a photon in the other was created with 100% certainty. In good experiments, it is possible to collect up to 70% of these heralded photons. We therefore write that conditional $P(\text{detection}_1|\text{emission}_2) = 0.7$, where 1,2 are the mode numbers. Similarly, $g_{\text{conditional}}^{(2)}(0) = 0.01$.

One can think of such a source as a source of pulsed ‘single photons’, where one learns about the presence of a good single photon (with $P_{\text{register}} = 0.7$ per pulse) by seeing a click in the other mode. Most experimenters use these sources and call them single-photon sources. This substitution may be justified from an operational viewpoint, but it makes a big difference from a foundational viewpoint.

From the viewpoint of self-(in)consistency analysis of quantum physical entities, by using heralded photon sources, experimenters try to minimize self-inconsistency by considering conditioned events. This is a crucial departure from the original event structure of quantum formalism, which is based on the assumption of the existence of individual quantum systems and uses event algebra (in fact, Boolean) to describe measurements of a single observable in such systems. Moreover, 30% unused pairs also destroys consistency of the event structure of yes-no experiments, i.e., we can claim that there is no Aristotelian objectivity with logical atoms.

Finally, we emphasize that, although the value $g_{\text{conditional}}^{(2)}(0) = 0.01$ is relatively small, the number of coincidence clicks is still non-negligible. Hence, we can repeat considerations of section 6 and derive non-objectivity of photonic observables from self-inconsistency of theoretic entities with respect to observables. Here the probability of coincidence also has a nonzero low bound, which, of course, depends on the experimental setup. It depends on so many technicalities that its calculation is really a nontrivial task. First and foremost, one needs to know the number of pairs generated per second. One can expect that $g_{\text{conditional}}^{(2)}(0)$ is higher for brighter states and lower for dimmer states. Losses in both heralding and the experimental channel are also important as well as properties of down-conversion. If one operates with a single-mode source, the noise photons will have thermal and not Poisson statistics. If one had a low mode number, the statistics would be a finite sum of thermal states, and if one had an infinite number of modes (broad background), the background would become Poissonian. Hence a $g_{\text{conditional}}^{(2)}(0)$ value would range by a factor of 2 (single-mode thermal state versus pure Poisson) for the same $\mu$, where the latter is the average number of photons per pulse. And—sure enough—in the presence of technicalities, such as loss, jitter, and uncorrelated noise, exposure time (time window) would matter.

10. Self-inconsistency of dichotomous quantum observables in light of the random field model of quantum phenomena

It is obvious that one can ignore our analysis of self-consistency of quantum phenomena by regarding the problem of the coincidence clicks as a purely technical problem of the elimination of noise, i.e., having no fundamental value. This problem can have a fundamental value only under the assumption that this problem cannot in principle be solved by improving technologies for ‘single-photon’ sources and detectors. Such an assumption cannot be justified within QM. However, there are some logical reasons supporting this assumption (sections 7 and 8). In particular, one can present some motivations for it by going beyond quantum formalism and considering prequantum (classical probabilistic) models reproducing quantum probabilities. The first reaction to such a comment would be that, as a consequence of various no-go theorems, such prequantum models do not exist; or if they exist, they have to be nonlocal as, e.g., Bohmian mechanics. According to Einstein, we reject such an ambiguous notion as nonlocal realism. Therefore, we discuss only local
prequantum models. Of course, such models have to be nonrealistic in Bell’s sense, i.e., non-objective in our terminology. We remark that Bell’s terminology ‘realism’ in connection with the problem of hidden variables is a bit ambiguous. He definitely discusses realism of quantum observables expressed in terms of hidden variables. However, realism can be recovered on the level of hidden variables if quantum observables are not expressible in terms of such additional variables. The notion of (non)objectivity is related only to quantum observables.

Thus, we want to discuss a non-objective model with hidden variables. The key point is that such a model will be self-inconsistent at the level of measurements formulated in the yes-no logics and the Aristotelian hypothesis of objectivity constructed for logical atoms. In spite of such features as non-objectivity and self-referentiality, which are pathological in the classical world, our model is very natural. In fact, there is nothing more natural if one wants to arrive at quantum physics by departing from classical theory. Non-objectivity in the Aristotelian sense and self-referentiality on the level of observations are strange only for classical mechanics of particles. And we consider waves instead of particles. This approach was originally explored by Schrödinger, but later he gave up. We were able to resolve the problems that pressured Schrödinger into accepting the probabilistic interpretation of the wave function (due to Max Born), in particular, the problem of the wave modeling of composite systems.

In short, in our model, which is known under the name prequantum classical statistical field theory (PCSFT) [53–61] quantum systems are symbolic representations of classical random fields fluctuating at time and space scales that are essentially finer than quantum lab scales. Such fields, by interacting with detectors of the threshold type, produce clicks. These clicks are interpreted as quantum events.

In PCSFT, the irradiance of a beam of light is only an indication of its average state. If we could magnify local states, we would see a little bit of chaos. At some points, the amplitude of the waves is well below the average, and at others we get arbitrarily high spikes. In short, the field is ‘clumpy’ at the microscopic level.

Suppose we have a point-like detector. When the field crosses the plane of detection, it might happen that the local amplitude is close to average or lower. No detection is possible. It can also happen that we have an amplitude spike followed by several small crests. Again, the signal does not accumulate above the threshold and nothing happens. Yet there is a real probability that an amplitude spike will continue over several cycles. In this case, sustained resonance above the threshold will result in a detection click. Consequently, the pattern of detection is produced by the low probability of transient spikes in a continuous field. It is not true that we have single discrete entities at the moment and point of detection.

At the level of such events, PCSFT is fundamentally self-inconsistent. The probability of a coincidence click, i.e., matching of two trains of spikes (at the micro-scale) at two detectors, is nonzero, even theoretically. It decreases as the threshold increases, but even for a very high threshold a random field can produce matching spikes.

Moreover, one cannot violate Bell’s inequality and more generally represent quantum compound systems in entangled states by considering random fields propagating in a vacuum (at least in our model). One has to consider a random background field that is present everywhere (one may call it zero point field or vacuum fluctuations). This (classical) field contributes to correlations and, in particular, its presence affords the possibility of violating Bell’s inequality. This field has a random structure similar to the one of random field-signals representing quantum systems. Hence, a threshold detector ‘eats’ energy of combined spikes, signals combined with the background field.

Non-objectivity of such observables in random fields is a consequence of self-referentiality, the impossibility in general of assigning, say, polarization up or down. As a consequence of the presence of the random background field contributing irrediculously to threshold detection, the coincidence clicks appear irrespective of our manipulations of random field signals representing quantum systems.

11. Conclusion

Following Bohr, von Weizsäcker, Brukner, and Zeilinger, we have analyzed the problem of inconsistency between the classical language description of theoretical quantum phenomena based on Aristotelian-Russellian logics and the experimental structure of these phenomena, which is exhibited first of all in the complementary structure of quantum experiments (so-called wave-particle duality). We have presented this problem in the very general context of linguistic solipsism (Wittgenstein, Searle, and Austin) by emphasizing the role of performative propositions in scientific theories and, in particular, in QM. Such propositions are in general self-referent; attempts to use them in combination with Aristotelian-Russellian logics leads to inconsistency. We have argued that, nevertheless, it is possible to escape logical self-inconsistency of quantum performativity by appealing to the approach based on non-well-founded reality [25] (as opposed to the approach based on objective reality).

In this paper, we pointed out that the problem of self-inconsistency of QM is even deeper than the self-inconsistency implied by the principle of complementarity. The latter (see the presentation of the views of Brukner and Zeilinger in the Introduction) implies that, for a quantum system \( S \), it is impossible to assign truth values consistently to all propositions with respect to this system. We found that even the statement regarding the existence of a quantum system cannot be peacefully embedded in Aristotelian-Russellian logics. Our argument is based on the analysis of the experiment in ‘photon existence’, measurement of the coefficient of second order coherence. If positivity of this coefficient for experiments with the ‘single-photon state’ is interpreted as a foundational issue (and not just as a problem of noise and state preparation), then the operational definition of a photon as the click of a detector leads to self-inconsistency of QM.
self-inconsistency of coupling between the notion of QM as a theoretical formalism and the real experimental situation.

We also stressed the similarity between quantum mechanical and biological phenomena. Both are characterized by descriptions based on performative propositions, and they are self-inconsistent in the framework of Aristotelian-Russellian logics. Our discussion of biological systems is restricted to performativity related to the principle of complementarity, given the impossibility of consistently assigning truth values to all propositions regarding actions of a biological system.

An important part of our consideration was regarding the role of an experimenter’s free will in resolving (at least partially) the self-inconsistency of QM; we have pointed to the performative nature of statements related to ‘experimental technicalities’ such as the discrimination threshold and the time window. We have also analyzed the possibility of resolving the self-inconsistency of QM by going ‘beyond quantum’. So we have considered a model of the classical field type reproducing the basic predictions of QM, the so-called prequantum classical statistical field theory (PCSFT). According to PCSFT objectives, reality can be recovered at the subquantum level, in spite of the non-objectivity of ‘reality at the quantum level’.

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