A neo-Aristotelic (maybe) approach to quantum reality

Leonardo CHIATTI[1]

Неоаристотелевский (возможно) подход к квантовой реальности

Леонардо КЬЯТТИ

ABSTRACT. This article wants to propose some opinions on the nature of microphysical reality at the quantum level. These opinions are expressed in common language, without reference to mathematical formulas, therefore in the same spirit that animated Bohr in the drafting of his famous interpretation of 1927. Nevertheless, the path followed is significantly different. In particular, the alternation between quantum wave and interaction is suggested as an alternative to the complementarity principle. Although both terms of this alternation are elements of the same physical reality, only the interaction is traceable to spacetime and therefore belonging to the domain of phenomena directly accessible to experience. Referring creatively to Aristotle, a juxtaposition between quantum wave and information is suggested.

Keywords: quantum reality, complementarity principle, formal causation, wholeness, quantum jump

РЕЗЮМЕ. Предлагаемая статья содержит некоторые взгляды на природу микрофизической реальности на квантовом уровне. Эти мнения выражены на обычном языке, без ссылок на математические формулы; следовательно, в том же духе, который воодушевлял Бора при составлении его знаменитой интерпретации 1927 года. Тем не менее, пройденный автором путь значительно отличается. В частности, в качестве альтернативы принципу дополнительности предлагается чередование квантовой волны и взаимодействия. Хотя оба члена этого чередования являются элементами одной и той же физической реальности, однако здесь взаимодействие прослеживается в пространстве-времени и, следовательно, принадлежит к области явлений, непосредственно доступных опыту. Творчески ссылаясь на Аристотеля, предлагается противопоставление квантовой волны и информации.

Ключевые слова: квантовая реальность, принцип дополнительности, формальная причинность, целостность, квантовый скачок.

[1] Medical Physics Laboratory, ASL Viterbo. ITALIA.

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Introduction

Each area of scientific research is delimited by an ideal line that contains the arguments considered "legitimate" and which cannot be trespassed, without running the risk of getting lost in metaphysical speculations that do not fall within the field of interest of science. For microphysics this line was drawn by Niels Bohr in 1927 [Bohr, 1928], as part of his interpretation of the nascent quantum mechanics. This interpretation, however, has been the subject of numerous criticisms by many authors, including some of the founding fathers of quantum mechanics itself (such as Einstein, de Broglie, Schrödinger and many others). It is impossible to summarize here this almost century-old, and in any case very well known, debate. Instead, what we would like to do is to approach the theme in a new, fresh way, using the same expository style of Bohr, which privileged the ordinary language over the formal one; like him, therefore, we will practically make no use of formulas. At the same time, we intend to move the line of the speakable, which Bohr traced in correspondence with the observations performed with measuring devices, repositioning it in coincidence with the micro-events at the quantum level: the so-called "quantum jumps". With this we assume that such events are real and *knowable*, therefore potential object of a scientific description. This position appears more in line with the situation of the current research in this sector [Itano, Bergquist & Wineland, 2015].

This shift of the line has profound consequences on the way we see quantum processes. First of all, the quantum formalism (specifically, the concept of "wave function" or "quantum wave") becomes a possible description of an objective reality: the quantum reality or, even better, the quantum level of physical reality. It therefore no longer represents a purely "symbolic" instrument as assumed by Bohr. However, it can be argued that if the quantum wave represents something real, this "something" does not exist as an object in spacetime. In other words, we are led to assume a notion of physical reality that is not limited to the spatiotemporal theater within which the interactions between the elementary components of matter take place [Sassoli de Bianchi, 2021]. These components (electrons, photons, etc.) are intrinsically pre-spatial and pre-temporal and their ephemeral spatiotemporal manifestation coincides with the micro-events defined by their interactions: the quantum jumps. During these jumps, the quantum wave undergoes a discontinuous variation.

It is the task of a specific physical interpretation of the quantum formalism to provide a detailed description of the quantum level of physical reality, and to define the correspondence between the terms of the quantum formalism and the entities of this reality. This topic is beyond the limits of this article and will not be covered in detail here. What we are interested in highlighting, however, is that the spacetime ordering of events, which exists in a potential sense at the quantum level (as the spacetime dependency of the quantum wave) is brought into manifestation by quantum jumps. In other words, at the quantum level space and time are *potentially* contained within matter (wave). It is at the classical level that the situation is reversed and classical objects, consisting of persistent clusters of quantum jumps originating from the interaction between their elementary components, are contained in an *actual* sense in the spacetime materialized by these jumps. We could say that in quantum discontinuity matter ejects spacetime, which thus becomes its environment.

In this way we arrive at a completely different narrative from that of problematic Bohr's principle of complementarity: there is in fact an alternation between act and *potentia*, instead of their coexistence in an alleged dialectical relationship of complementarity. However, it should be noted that the conversion of potentia in act applies only to the spacetime structure which, contained *in nuce* in the quantum wave, becomes the spacetime of daily experience following its actualization in quantum jumps. For what concerns the relation between wave and jump as such, it is instead a causal relationship between two actualities expressed at two different levels of physical reality, only the second of which is directly accessible to experience.

This causal relationship is different from that expressed in the ordinary dynamic causality well known to physics today. The quantum wave can be thought as *information* (understood in a more or less Aristotelian sense) that defines the expressive possibilities of the content, represented by the quantum jump. This seems to us to be a more precise formulation of the famous suggestion proposed by Heisenberg in *Physics and Philosophy* [Heisenberg, 1962]. Naturally, the reference to Aristotle is here to be understood in a rather creative sense; the understanding of phenomena we are talking about requires new interpretative categories and their forced explanation in terms of conventional

Aristotelian physics is pointless. We must turn to the Stagirite as a source of inspiration for the construction of a renewed philosophy of nature that includes the aspects under discussion, rather than demanding from him a ready-made explanation of phenomena that in his time were not even imaginable.

The plan of the presentation is as follows. In Section 2 is presented the general scheme of the relationship between quantum waves and quantum jumps, emphasizing how each of these two elements is dependent on the other for its own definition. In the history of a specific quantum system these elements enter into a relationship of alternation, which is compared with the traditional principle of complementarity in Section 3. The interpretation of quantum waves as an informational phenomenon is outlined in Section 4. The general principles of the emergence of the classical level from the quantum background of waves and jumps are discussed in Section 5. Section 6 reports some final notes.

1. Waves and jumps

We will begin our conceptual exposition with the discussion of a very simple experiment, which involves the electron as an example of a typical quantum entity. It is possible to generate electrons in relatively simple ways, for example by heating a metallic filament. We can therefore imagine producing a single electron in this way and directing it towards a photographic plate, where it will generate a blackened point at the impact position. Quantum formalism describes the electron as a wave that, coming out of the electron source, that is the filament, propagates up to the photographic plate. This wave, associated with the single electron, hits on the entire plate, or at least an extended portion of it. At a certain instant the wave disappears, cancelling itself out everywhere except at a single grain of photographic emulsion, the one in which the incident electron is absorbed. This grain is the one that, at the end of the subsequent phases of photographic development, will turn out to be the blackened one. The phenomenon constituted by this discontinuous "jump" of the wave is called "quantum jump". Quantum theory does not allow predicting where the impact will occur, that is, which grain will undergo blackening: the quantum wave only defines the probability that the impact will occur within a given region of the plate. That is, it provides the probability of the several possible quantum jumps.

In summary, we have two events (quantum jumps) that can be associated with two distinct regions of space at two different instants of time. These events are the emission of the electron by the filament and the impact of the electron on the emulsion grain of the plate; in both cases, the quantum wave that describes the electron undergoes a discontinuous modification over time. These two instantaneous events are connected through the quantum wave propagation, which defines the probability distribution of the second event (*i.e.* the spatial probability distribution of the impact) conditioned by the first event (the emission). With regard to the experiment under discussion, the initial condition on the quantum wave consists of the wave coming out of the filament. This latter is defined by the methods of preparation (the arrangement of the filament) which are uniquely determined. This condition is therefore univocal (unlike what could be asserted by a relational approach) and independent on how the subsequent propagation of the wave is modified by accessories such as mirrors, lenses, screens, beam splitters, etc., arranged along the path of the electron. In this sense, the initial condition is an objective physical fact. An absolutely identical reasoning can be carried out for the final condition, consisting in the impact of the electron on the plate.

The propagation of the wave is, unlike the quantum jumps that it connects, a continuous phenomenon over time and which does not have a random character. It is described as the solution of an appropriate wave equation, uniquely determined once the initial condition has been assigned (or the final one, if the problem is studied in retrodictive terms). The instantaneous cancellation of the quantum wave (which is a spatially extended phenomenon), contextual to the impact, clearly demonstrates that it is a completely different entity from classical waves, such as sound waves or sea waves; these, in fact, absolutely do not present phenomena of discontinuity of this type. The instantaneous nature of quantum jumps, in turn, clearly demonstrates that the wave that is cancelled (or rather, collapsed into a more localized spatial region) is not an object placed in space; if so, its deformation would require a finite time and could not be instantaneous. This conclusion is confirmed by the quantum formalism, according to which the wave is not located in ordinary spacetime, but in a more abstract mathematical structure which is the enlarged space of configurations. This space is multidimensional, its dimensions being the spatial coordinates of all the particles making up the system and time. This space coincides with ordinary spacetime in the only particular case, that we consider presently, of a system consisting of a single particle.

We can therefore consider the quantum wave as a pre-spatial and pre-temporal entity, characterized by the fact that it encodes all possible sets of impacts obtainable at a given instant following a given initial preparation, each weighted with its relative probability; and for this reason it depends on the coordinates of all particles and on time. The wave, in other words, *potentially* contains all possible sets of impacts. It therefore contains, always *potentially*, the spatiotemporal relationships between the impacts belonging to each of these possible sets. These relationships are actualized when a certain set of impacts is brought into being by a quantum jump. Of course, in the simple, here considered case of a single particle, what the wave potentially contains are the different possible determinations of the single impact that particle can undergo. What is actualized in a quantum jump is then a specific impact, characterized by a specific spatial position and by a specific instant of occurrence. That position and that instant, previously *potentially* contained in the wave, are *actualized* by the jump into ordinary spacetime, as the position and instant of the impact actually occurred.

It is necessary to dwell on this aspect, to avoid misinterpretations. Spatial position and instant of the impact *are potentially contained in the matter*, constituted by the wave. At this stage, matter therefore potentially contains space and time, and in this sense it constitutes a pre-spatial and pre-temporal reality. The quantum jump actualizes a specific impact with a specific position and instant of occurrence, which become (together with the positions and instants of innumerable other impacts actualized in other jumps) elements of an actualized spacetime. This is the spacetime of our experience, in which the material phenomena directly accessible to our experience, such as the blackening of the emulsion grain, find their place. The "classical" objects of our daily experience (made up of clusters of innumerable quantum jumps induced by the continuous interactions between the innumerable elementary particles that constitute them) thus appear contained in spacetime. At this stage, therefore, matter *is actually contained in spacetime*. This inversion of the situation (spacetime is first potentially contained in matter, then matter actually becomes contained in spacetime) is the substance of the transition from quantum reality to the classical reality of our ordinary experience.

It is also important to point out that this inversion can be interpreted in terms of a passage from *potentia* to *act* only as regards the relationships of a spatiotemporal nature between events. As for matter, it is instead the mutual conversion of two of its actual states: one (the wave) pre-spatial and pre-temporal, the other (the impact) spatiotemporal. The quantum jump is therefore an ordinary physical phenomenon, although not a classical one, which connects two actual states and this makes possible, at least in principle, to formulate a theory explaining it. This path seems more promising than that indicated by Heisenberg in *Physics and Philosophy* [Heisenberg, 1962], the clarification of which is problematic, as evidenced by an examination of the current literature on the subject [Silva (2013), Bishop & Brenner (2017), Driessen (2020), Kožnjak (2020), Strumia (2021)].

2. Alternation or complementarity?

In a quantum jump the wave undergoes a discontinuous variation; the wave coming out of the jump acts as an initial condition for the subsequent propagation up to a further jump. The process of conversion wave → jump → new wave takes place at the microscopic level, being ultimately an interaction between elementary particles, and it is objective: it does not require observers or observation equipment. This process constitutes an event without duration, which opens a new finite interval of pre-spatial and pre-temporal existence. The actualization of the microscopic quantum entity, in the previous example the impact of the electron on the plate, is therefore ephemeral. In the quantum description there are no corpuscles or other persistent objects contained in actualized external spacetime. It therefore makes little sense to speak of a "wave-corpuscle" dualism, an expression however consecrated by use.

The sequence $\cdots \rightarrow$ wave $\rightarrow$ jump $\rightarrow$ wave $\rightarrow$ jump $\rightarrow \cdots$ clearly constitutes an alternation between two different states of the quantum system: the one actualized in the jump (without duration and ephemeral) and the one actualized at the pre-spatial and pre-temporal level. If we really wanted to use the term "corpuscle", we should speak of "wave-corpuscle alternation"; but such an expression is unusual, while the expression "wave-corpuscle complementarity" coined by Bohr is much more common. There is a big difference between the alternation and complementarity of two terms. If two terms alternate, when there is one there is no other: they succeed each other like day and night. If two terms are complementary, then they must both be present in any given situation. In the first case the relationship between the two terms is defined by the binary formal logic, in the second case we could be tempted by the seduction of dialectical logic, as was Bohr. Alternation and complementarity do not seem reconcilable and we have elucidated the reasons for the alternation. We now come to expose the weaknesses of complementarity.

To get into the topic, let us reconsider the simple experiment outlined in the previous Section. Let us complicate it by interposing, between the filament that emits electrons and the photographic plate, a screen opaque to electrons with a thin slit. Now, of course, only the electrons passing through the slit can arrive on the plate. Bohr's dialectical artifice consists in defining the behavior of the electrons crossing the slit as "corpuscular" because to arrive on the plate they *have to pass there*. This possessing, albeit in an ephemeral way, an attribute of position is considered by him as synonymous with corpuscularity.

Now let us repeat the experiment in another variant, replacing the intermediate screen with another having *two* slits. Now, only the electrons that pass through the double slit arrive on the plate and can be recorded on it. But, of course, we cannot say "only the electrons that cross *one* or *the other* of the two slits arrive on the plate and can be recorded on it". Such a sentence would suggest that electrons are persistent objects endowed with a spatial trajectory and that therefore pass through only one of the two slits (although we may not know which one). We have already seen that this is not the case: in crossing the double slit the electron is in a wave state and it crosses both the slits, so that it comes out as a combination of two interfering waves. The interference pattern can be evidenced through the distribution of the impact points of single electrons on the plate [Merli, Missiroli & Pozzi (1974); Merli, Missiroli & Pozzi (1976)]. Bohr argues that in this case the electron is a wave because interference is a wave property.

However, diffraction is also a wave property, and if one examines the distribution of impacts on the plate when a single slit screen is interposed, a diffraction pattern is clearly seen [Merli, Missiroli & Pozzi (1974); Merli, Missiroli & Pozzi (1976)]. This is in accordance with the fact that also in this case the electron incident on the intermediate screen is a wave. Among other things, diffraction is only the result of the interference of the different elements of the wave front that crosses the single slit [Born & Wolf, 1959]. The distinction between diffraction and interference, therefore, although technically useful, is not fundamental. Thus, Bohr's dialectical artifice turns out to be largely fictitious: the availability of which way information on the electron does not characterize its wave or corpuscular nature.

Once it was decided to play Bohr's game, the road would be marked. We would have a corpuscle with a single-slit apparatus, a wave with a two-slit apparatus and therefore an indefinable entity that is a wave or a corpuscle depending on the apparatus used to investigate it. The fact that the attributions "wave" and "corpuscle" are manifested with incompatible experimental apparatuses allows to avoid a direct contradiction and thus we arrive at the principle of complementarity. In accordance with this principle, the unknowable electron becomes knowable to the extent that, by comparing the results of investigations carried out on it with different and even incompatible experimental equipments, a pattern of characteristic complementary properties emerges. As we have seen previously, such a dependence on the measurement apparatus is completely unjustified because the (wavelike) nature of the electron is fixed by the initial condition constituted by the wave leaving the filament. As we have already seen, this condition does not depend on the choice of the apparatus downstream of it, interposed between the filament and the plate. This choice, in fact, only affects the propagation of the electron, which in any case remains undulatory.

To give an idea of the difficulties induced by Bohr's categorization, consider the following experiment performed by Grangier, Roger and Aspect in 1986 [Grangier, Roger & Aspect, 1986]. Let us imagine sending a single photon on a semi-silvered mirror BS oriented at 45 degrees respect to the direction of arrival. The quantum wave Ψ of the photon exiting the mirror is the sum of a transmitted wave Ψ_{tr} and a reflected wave Ψ_r, which will take two different and orthogonal paths; that is $\Psi = \Psi_{tr} + \Psi_r$. Now let us imagine (Figure 1) that these two waves hit two distinct detectors D_1 and D_2. Quantum mechanics teaches us that only one of the two counters clicks, revealing the passage of the photon. This conforms to what one would expect when considering the photon as a corpuscle, and Bohr would therefore say that in this experiment the photon reveals its corpuscular nature. Now let us remove the D_1 and D_2 detectors and replace them with the two total reflection mirrors of a Mach-Zender interferometer (see Figure 2). These mirrors recombine the partial waves Ψ_{tr} and Ψ_r in correspondence of a second semi-silvered mirror BS_2. This recombination leads to an interference between these waves, detectable through the detectors D_3 and D_4. This conforms to what one would expect considering the photon to be a wave, and Bohr would therefore say that in this experiment the photon reveals its nature as a wave. Now, the point is that we can pass from the second variant of the experiment to the first simply by obscuring the two total reflection mirrors by interposing the two detectors D_1 and D_2 and this can be done *after* the photon has interacted with BS. Therefore, it is argued, the choice of the nature of the photon does not occur in BS, but is defined by the totality of the experimental apparatus adopted. That is, it is "contextual".

Of course, there is no any contextuality of this type: the relationship $\Psi = \Psi_{tr} + \Psi_r$ holds in both variants of the experiment. What is propagated is the quantum wave of a single particle that can originate only one impact, simultaneously cancelling itself out everywhere as a result of this impact. Thus, in the first variant the impact will occur on the D_1 detector or on the D_2 detector; in the second variant it will take place on detector D_3 or on detector D_4. In the first variant there will be no interference because the partial waves do not overlap; in the second variant there will be interference because they are recombined.

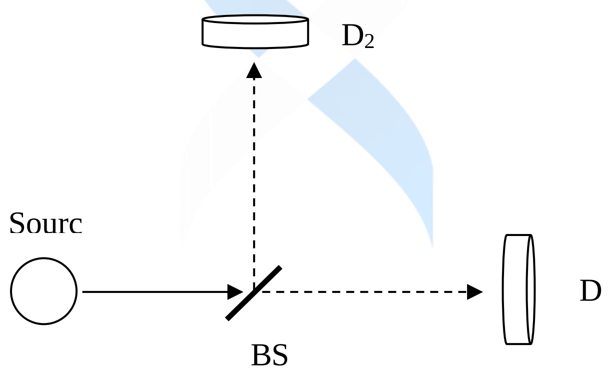

Figure 1. The first experimental set-up

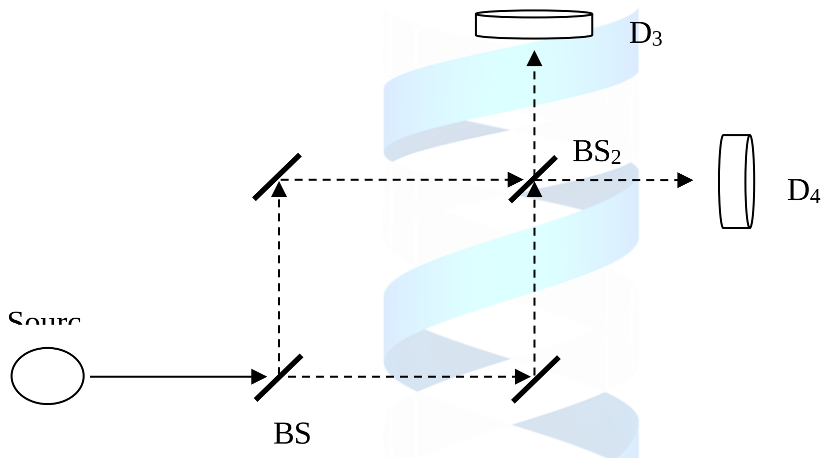

Figure 2. The second experimental set-up

3. Quantum waves as information

Having established the wave-jump alternation as a frame of reference, we can now address the key topic of this work. The pre-spatial and pre-temporal state, which quantum formalism describes as a wave, includes all the possible configurations of quantum jumps compatible with the initial preparation of the system, each weighted with its probability of realization. For example, the wave does not contain the quantum jump configurations incompatible with the initial preparation. An interaction can actualize, at a given instant, only one of the configurations included in the wave. The wave therefore represents an informational constraint on the possible configurations of quantum jumps. *The wave is information*. From this point of view, it has characteristics in common with a formal causation in the Aristotelian sense, but passing from this vague analogy to a precise correspondence is problematic, as evidenced by the numerous discussions in the literature on this topic [Silva (2013), Bishop & Brenner (2017), Driessen (2020), Kožnjak (2020), Strumia (2021)]. We can however note that the causal connection between the pre-spatial and pre-temporal state and the actualized state (the blackened grain of our initial example) is certainly different from the dynamic causality evolving the first state in a continuous and deterministic way. Penrose speaks respectively of process R and process U [Penrose, 2004], distinguishing them clearly. Our proposal is therefore to interpret quantum waves as information available to quantum jumps, and to interpret these latter (Penrose's R processes) as a new form of causal connection in physics. We note that this connection, unlike the dynamic one, does not act in the "actualized" temporal domain because in this domain the quantum jump has no duration.

The wave actually introduces a principle of "coherence" or "wholeness" [Bohm, 1980] in the implementation of quantum jumps, an aspect that is clearly marked in the first version of the experiment by Grangier, Roger and Aspect discussed above. Only one of the two counters clicks, because the wave $\Psi = \Psi_{tr} + \Psi_r$ outgoing from the semi-silvered mirror BS is the sum of two terms corresponding to only two alternative possibilities: Ψ_{tr} (the photon is transmitted, the detector D_1 clicks) and Ψ_r (the photon is reflected, detector D_2 clicks). There is no third addend corresponding to the simultaneous transmission *and* reflection of the photon, with the consequent clicking of the two detectors, and this determines the anticorrelation between the clicks of the two detectors. It seems to us that this feature of wholeness based on information may constitute a relevant topic in the context of natural philosophy.

It should be emphasized that the concept of "wholeness" to which we refer represents a form of coherence *between events, not between objects* (which, as we have seen and as will be discussed in the next Section, do not exist in the domain of quantum reality). The wholeness can therefore manifest itself in a transtemporal form, as a connection between different events involving the same quantum entity. An example is the spontaneous radiative decay of an excited system (nucleus, atom or molecule). The system is described by a wave associated with the present excited state. If there is an interaction capable of connecting the excited state present to the ground state, then the wave associated with the present excited state "feels" the wave associated with the ground state that is not yet actualized. The ground state then becomes a possible future of the system, and the system begins to move towards the realization of that future. This is how the decay of the system towards the ground state begins: a spontaneous process that does not require external intervention (the only condition constituted by coupling with the radiative field is required). In quantum formalism, this *entelechy* is formally described by the element of the interaction matrix between the initial (excited) and final states. As an effect of this process, the wave associated with the system becomes the sum of the two waves associated with the initial state and the final state, in which the term corresponding to the final state gradually becomes prevalent according to a definite law. This gradual evolution towards the final state is suddenly truncated (at an instant that cannot be predicted) by a quantum jump that produces an outgoing wave identical to that associated with the final state. The wave corresponding to the initial state (already reduced by the gradual evolution mentioned) is zeroed. This jump constitutes the actual decay, revealed by the emission of radiation consisting, in the simplest case, of a single photon.

The photon is always emitted in one of the available stationary states of the electromagnetic field. The decay can occur in an ultra-short optical cavity that suppresses most of the possible modes of oscillation of the electromagnetic field; the photon is however always emitted in one of the surviving modes. In other words, the wave associated with the final state of the system, towards which the system moves and on which the system is projected by the quantum jump, contains a state of the emitted photon that is *already selected* among the surviving states. This shows that at the beginning of the process described here, the wave associated with the final state already contains information on the permitted modes of the cavity; a truly spectacular display of wholeness.

4. Everyday reality

One can legitimately ask how the classical reality so familiar to us emerges from the bizarre world of quanta. The point seems to be constituted by the substantial difference between quantum reality and classical reality under the ontological profile, although they are certainly two faces of the same physical reality.

Quantum jumps are interactions between elementary particles of matter, such as electrons, protons, and so on. The existence of jumps defines the existence of a level of elementary particles as entities involved in these jumps. Jumps convert incoming quantum waves into outgoing quantum waves. Therefore, quantum waves understood in the proper sense are attributable to elementary particle systems without internal quantum jumps, such as the elementary particles themselves and their bound states (isolated or with negligible energetic exchanges with the outside compared to their binding energies). Quantum formalism attributes to these systems waves that can be defined in terms of the waves of their constituent elementary particles, through a construction known as "entanglement". This is for example the situation of microscopic entities such as atomic nuclei, atoms or molecules, and also the situation of macroscopic entities such as the superfluid phase of liquid helium or the supercurrent in superconductors.

For systems made up of elementary particles that interact with each other, originating quantum jumps, a description in such simple terms is not possible. A quantum treatment of these systems would require to take into account both the continuous evolution of the waves associated with their elementary components (with the related entanglement phenomena), and their discontinuous variation caused by *internal* quantum jumps. It is clear that systems of this type, in practice almost all macroscopic systems with many particles, cannot have an associated quantum wave in the strict sense of the term. This wave, in fact, could not satisfy the necessary condition which a quantum wave in the proper sense should satisfy, that is, be converted by a single quantum jump. In other words: the particles that make up a macroscopic system are divided into distinct groups. There is an entanglement relationship between the particles of each group and they are therefore associated with the same wave; but between particles belonging to distinct groups there is no such relationship and therefore they are associated with distinct waves. Some of these waves can be converted into a single jump, but this event leaves the waves associated with the other groups unchanged. The system cannot be described by a single wave, because this wave should express an entanglement relationship extended to all the particles making up the system, and it should be converted by a single quantum jump. But this is not possible due to the absence of entanglement between the different groups of particles making up the system, each associated with a different wave.

The extreme situation is then represented by those cases in which the interest is directed not to the system itself as a complex of waves and jumps, but to the set of average properties of its internal quantum jumps. This is possible when the spatial density and the frequency of the internal jumps in the system are so high that a description of the evolution of their local mean properties by an approximation of the continuum becomes justified. This description then identifies an *object*, understood in the classical sense, which follows the laws of classical mechanics (within the limits established by the uncertainty principle). Objects of everyday life such as chairs, tables, animals, people belong to this category.

The limits of the quantum world are therefore the limits of entanglement, and they are defined by the quantum jumps occuring within the system. To make the concept understandable without using complicated formulas, let us return to the case of the semi-silvered mirror in the first variant of the Grangier, Roger and Aspect experiment. We have seen that the photon exiting the mirror is described by a wave which is the superposition of two of its alternative futures: the one in which the photon is transmitted and the one in which it is reflected. This is possible because the photon is a quantum entity; it is, in effect, an elementary particle. In the first version of the experiment, only one of these two futures is actualized. In the second version of the experiment, none of them is actualized: they are recombined without being actualized. In both cases, however, the entire history of the system is that of a single wave that undergoes a single discontinuous variation in a single quantum jump (the absorption on the detector). The photon has no internal jumps, due to its elementarity.

Now let us replace the photon with a cat. A cat can be dead or alive. Can we associate the cat with a quantum wave defined as the sum of two waves, one associated with the live cat, the other with the dead cat? That is, can we treat the cat, *which is an object*, as if it were a quantum entity? Here two observations are in place. The first is that being alive or dead is an *actual property* of the cat, not a possible future for it. This is because the cat is an object, and therefore an actuality that is composed of a myriad of actualizations (the quantum jumps inside the cat). Therefore, the sum would not express two possible alternative futures, but the simultaneous realization of two alternative actual properties, thus violating the principle of non-contradiction. Second, neither of the two partial waves, ascribed to the live cat and the dead cat respectively, could be converted by a single quantum jump. In fact, a quantum jump converts a quantum wave in the proper sense, not a complex of other quantum jumps. Jumps operate on waves, not on other jumps. The partial waves therefore could not even *be generated* by a quantum jump, which is another way of saying that they cannot be physically produced. We can paraphrase the situation by saying that if we decided to describe the two states of the cat with waves, these would not be quantum waves in the proper sense and therefore could not be subject to quantum jumps or superposed as possible futures of the cat.

Finally, we note, without deepening the concept, that since the two partial waves cannot represent alternative possible futures of the cat, they cannot even enter into an entanglement relationship with the possible futures of a quantum system such as, for example, a radioactive atomic nucleus, to produce the possible alternative futures of the cat + nucleus system. This solves the difficulty raised by Schrödinger [Schrödinger, 1935].

Conclusions

In these brief concluding notes we would like to try to put what we said in the previous Sections in a broader context, with particular reference to biocosmological studies. Let us therefore begin with the reasons that inspired and guided our research. These reasons follow what appears to us to be an honest answer to a question that could be posed in these terms: did physics originating from the scientific revolution of the seventeenth century really replace Aristotelian physics, which had dominated the scene for about two thousand years?

If we look at the natural sciences in exclusively analytical terms, and therefore at the quantity and quality of the data they collect and the interpretative models they develop, the answer is undoubtedly positive. Our analytical knowledge grows every year by the same amount as it did in a millennium in the times before the scientific revolution. Most of the things we know today were not known in those days or even contradict the science of the time. By way of example, space flight was inconceivable in Aristotelian physics. Aristotle's eternal and crystalline skies, in majestic rotation around the Earth, have little in common with the haunted scenarios of black holes and solar storms that thrill today's researcher. Aristotelian physics has little to say with respect to the physical problems currently investigated. The attempts, however interesting, to recover it [Selvaggi, 1996] have left the professional physicists quite indifferent, and remain confined to religious university institutions without contact with current scientific research.

However, if we look at the situation from the point of view of the synthesis of knowledge, it is reversed. Aristotelian physics was not only an analytical description of phenomena, but a complete system of natural philosophy whose pivot was represented by the notion of the cosmos; a notion that cannot in any way be replaced by the subsequent one of universe. In the idea of the cosmos there is the notion of an organic unity of the natural world (similar in some ways to the notion of *wholeness* presented here in a specific context) which paves the way for a search for *meanings*. A synthetic type of research conducted through analogical and comparative methods complementary to the analytical ones, which represents a dimension absent from today's science and which, however, is urgently needed [Strumia (2007), Khroutski & Klimek (2018), Khroutski & Tasić (2021)].

This paper is intended to be a small contribution in this direction. The attentive reader will have noticed that most of our effort has been to refocus the discussion on the topics covered, trying to avoid conventional narrative which is, in our opinion, obsolete. Our proposal to replace the concept of complementarity with that of alternation has been detailed in the attempt of make its advantages evident. Among these there is the possibility of interpreting quantum waves as informational structures and of reintroducing, at a fundamental level, a sort of formal causation not in contradiction with the dynamic causality well known and accepted by modern physicists.

This is the point of the path we have reached so far. We have not attempted a philosophical elaboration of the notion of information thus introduced, because we believe that such a task must be taken over by professional philosophers. It is our belief that Aristotle represents the inevitable starting point for this research, but we also note that the attempt to forcibly bring the topics discussed here back to the "historical" Aristotelian categories seems to lead to philological disputes that risk remaining essentially sterile. An examination of the pertinent literature [Silva (2013), Bishop & Brenner (2017), Driessen (2020), Kožnjak (2020), Strumia (2021)] has convinced us that a simple revival of Aristotle's model of the four causes is not adequate, as well the re-proposition of the *potentia*, albeit in the forms tempered by the elaboration of St. Thomas. We do not find ready answers in the classics of Aristotle and St. Thomas, and we believe that a lot of creative work is necessary to arrive at an elucidation of the whole question on a philosophical level. Our hope is that we have provided a useful starting point for those who wish to investigate in this direction.

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