How Quantum Mechanics Suggests New Insights In Metaphysics and Natural Theology

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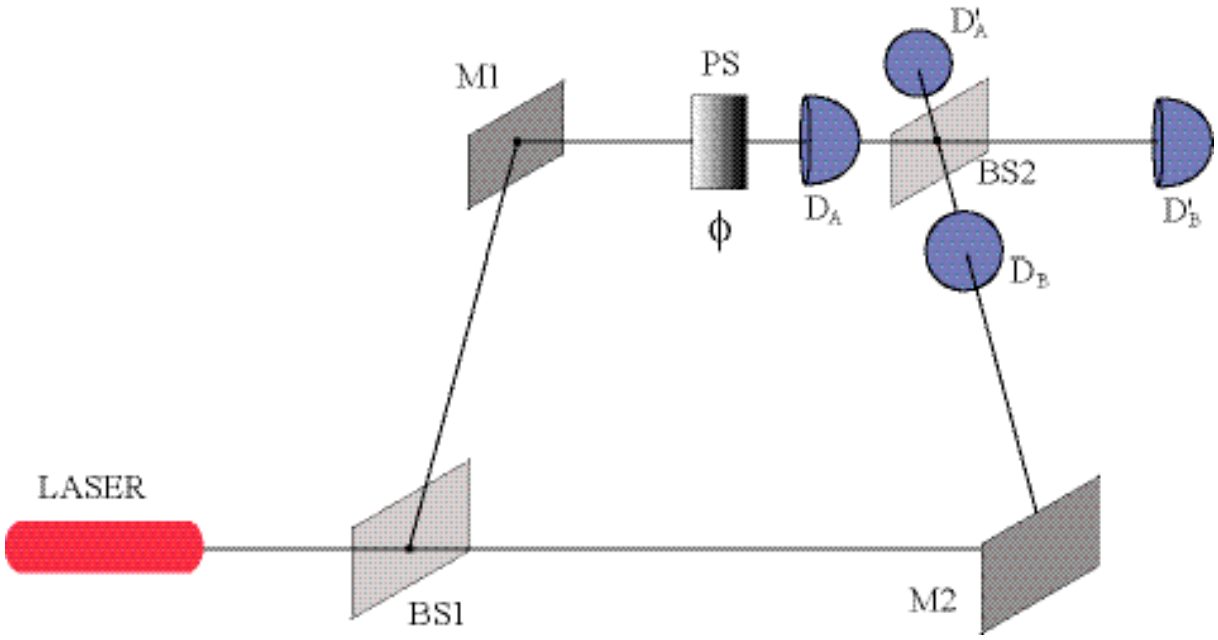
In this paper, I examine complementarity, a concept introduced by Niels Bohr for interpreting quantum mechanics (QM). I will explain that QM has three basic features: the event, the correlations, and the dynamics. These features stem from the nature of quantum information, which is a general paradigm (far more general than classical information) covering the emergence of any dynamic system. It can explain the arising of classically physical systems, but also the emergence of life. If these features of QM are so general, we may ask how philosophers may perceive them. Alfred North Whitehead and Charles Sanders Peirce took this path. Dynamics can be understood as a trade-off between local events and "non-local" quantum correlations, results that were partly anticipated by Peirce and Whitehead. Moreover, according to Peirce, the reason why the three features of QM are so general is that they are *imago Dei*; that is, they show a Trinitarian structure. I will also briefly consider some consequences for natural theology.

As is well known, Bohr (1928) developed the idea that, in terms of classical physics, a causally complete description of a physical system has two features: spacetime coordination and the causal, dynamic definition of the system. He pointed out that the unity of these two claims breaks down in quantum mechanics, and so we cannot obtain simultaneously the exact individuation of a system's position and its dynamic description. This is the basis of the complementarity principle. However, there is a certain ambiguity in Bohr's expressions, so that we could reformulate this principle by saying that there is a complementarity between event (an event is by definition a space-time localized phenomenon) and the wave-like behaviour of the same system.

The delayed-choice experiment proposed by Wheeler (1978: 1983) sheds light on this point. Consider a Mach-Zender interferometer (see figure). A light beam emitted by the laser on the left is split into two paths by a beam splitter (BS1), a half-silvered mirror that partly transmits and partly reflects an incident beam. The two beams are then reflected by full mirrors, M1 and M2. The phase shifter (PS) tunes the phase between the two components. The photons will be detected after the two beams are recombined and split again by a second beam splitter (BS2).



In Wheeler's version of this setup, the final detectors may be switched from the 'ordinary' positions DA' and DB' to positions DA and DB before BS2. This may be done after the beam has already passed BS1. In the arrangement DA-DB we detect the (corpuscular) path of the photon, and this represents an event. Instead, in the arrangement DA'-DB', we detect the (wave-like) interference, and this cannot consist in an individual event: In fact, in order to obtain and interference, in the general case many experimental runs are necessary. In general, it is impossible to measure the wave--like features (the wave function) of a single system (D'Ariano/Yuen 1996). Obviously, the two typologies of detections are incompatible, according to Bohr's prediction.

In order to understand better the specificity of the second typology, let us say that the results obtained by measuring the wave-like properties in a delayed-choice experiment and by doing the same an "ordinary" (not delayed) interferometry experiment show no difference. In other words, we are totally free to perform delayed-choice experiments (i.e. to displace the detectors) without altering quantum predictions. This teaches us a general lesson: There are time intervals - in our case, the time interval in which the photon travels from BS1 to the detectors - where we cannot assume that an event happened, whereas, after this interval, an event may have occurred - the photon has been registered by D1 or D2. On the other hand, we cannot have an input photon before BS1, a detection output at D1 or D2, and nothing between the input and the output. We are then forced to admit that there must be a reality also before an event has been registered (at D1 or D2), since events can only come out from some form of reality. What is then this form of reality? This reality is the superposition-state (in our experiment, the combination of lower and upper path of the interferometer), the wave-like nature of the photon, i.e. the initial state and the evolved state until the detectors.

As I have said, we cannot detect directly the 'superposed' reality (see again D'Ariano/Yuen 1996) but only infer it indirectly (see Auletta/Tarozzi 2004). This is precisely because any measurement is local in nature. However, we should then carefully distinguish between two features. One thing is the *reason* for the quantum (detection) event: I have said that there are no reasons why we obtain this result and not another. The other thing is *if this result comes from nothing*. This is impossible. Therefore, there must be a form of reality that somehow establishes the *general* (but not the particular) conditions from which the event emerges.

Whereas the detection event is discontinuous and unforeseeable, the superposition is a form of continuity (in fact, as I have said, a superposition of, say, two states allows all linear combinations of these two states). Moreover, these states associated with possible measurement outcomes, as components of a superposition, cannot be separated: This is a notable difference from classical physics, where no probability of an outcome 'interferes' with another. What is then complementarity? Complementarity is a relation between the initial state and any of the following states before the interaction with the detectors (anyone of these states comprehends, in terms of probabilities, all the possible measurement results in a continuous way), on the one hand, and the final detection event, on the other (which, in an abrupt way and without apparent reasons, is a "decision" of a result in particular). In this sense, an event is a selection of one among a huge number of possibilities "encapsulated" in the initial state of the system.

Dynamics is the joint, the connection between these two complementary features, between the unforeseeable detection event and the initial superposed (relatively to the measured observable) or entangled, state, which is "non-local" because of the interference of probabilities. In order to understand this, we must not consider the photon as if it were an isolated system. Instead, it is necessary to consider the total system comprehending the photon, the apparatus, and also the environment (any quantum system is always correlated to the environment). It is this dynamics that allows the result to be either a result of the measurement of the path or of the interference pattern. It is also the dynamics that may either destroy an entanglement or also constitute it, that may allow a measurement outcome but also annihilate this possibility by returning to the initial state through reversible dynamics (the so-called quantum eraser). In other words, dynamics should be considered the trade-off between events and the continuity of quantum correlations. There is also another reason because it should be so. Contrary to what Bohr thought, there is an infinite number of intermediate possibilities between a pure corpuscular and a pure wave-like behaviour (Mittelstaedt *et al*. 1987), so that these must be understood as limiting cases of dynamic behaviour.

In quantum mechanics there are therefore three fundamental features to be distinguished (see also Auletta 2004a): (1) the abrupt, discontinuous, local production of an event, (2) the relational, continuous, "non-local" dimension of

superposition and entanglement, and (3) the dynamical trade-off between these two opposite features.

My point is that these features are not only features of quantum reality but also features of the world in general. These features are, in fact, the direct consequence of the nature of information in quantum mechanics [see Auletta 2004b-c] - and any quantum system represents information. The initial (wave-like) state may be seen as an amount of potential information that contains all possible measurement outcomes. An event may then be seen as a form of selection of this initial amount of potential information. On the other hand, entanglement may be seen as a form of mutual information, i.e. the different systems that are entangled share common information. The structure of matter arises when several quantum systems interact. In this case, while entanglement reduces to zero, a form of classical mutual information arises and the atomic, molecular, and so on, structures emerge. On the other hand, living organisms may be seen as specific form of selection of information (the epigenesis, the perception, the development of the brain are all forms of information selection). Although 'dead' matter stresses more the mutual-information aspect while life more the selection-of-information feature, both aspects are always present in any dynamical system of the world.

If these there aspects are so general, it may be interesting to see if they have been perceived, even if in a confused form, by great metaphysicians. The answer is yes. In particular, I wish to introduce here Whitehead and Peirce. It is stunning to realize that Whitehead spoke (1929: 169) at almost the same time that Bohr published his article (and to my knowledge neither Whithead nor Bohr knew of each other's opinions) about the fact that (classical) science requires scientific observations that have to do with what Whitehead calls "presentational immediacy"—the location of things in the present time (see 1929: 61-70 and 121-26)—and with scientific theories (and laws) that have to do with causal efficacy. And this is perhaps the place to shed some light on the misunderstanding of causality. Causality may be only the result of the convergence between observation and law, between events and correlations. The latter allow the possibilities from which events may emerge. The important point is that Whitehead completely agrees with the idea that at any moment the world makes decisions that represent a selection of the potentialities that the past state allowed (1929: 42-46).

Perice introduced the concepts of *firstness*, *secondness*, and *thirdness*. About *firstness*, he said (CP 1.302): "The idea of First is predominant in the ideas of freshness, life, freedom. The free is that which has not another behind it, determining its actions. …" And (CP 1.357): "It must be initiative, original, spontaneous, and free; otherwise it is second to a determining cause. … It cannot be articulately thought: assert it, and it has already lost its characteristic innocence; for assertion always implies a denial of something else. Stop to think of it, and it has flown! What the world was to Adam on the day he opened his eyes to it, before he had drawn any distinctions,

or had become conscious of his own existence—that is first, present, immediate, fresh, new, initiative, original, spontaneous, free, vivid, conscious, and evanescent." I stress here the idea that the first is not determined by the preceding conditions, as in the case of a quantum-mechanical event.

About *secondness*, Peirce wrote (CP 1.322): "The second category that I find, the next simplest feature common to all that comes before the mind, is the element of struggle. … Now there can be no resistance where there is nothing of the nature of struggle or forceful action. By struggle I must explain that I mean mutual action between two things regardless of any sort of third or medium, and in particular regardless of any law of action." The stress on struggle remains from classical (mechanical) science. The important point, I think, is that secondness implies relations between several things.

It is also interesting that Peirce developed the idea that individuals (and events) are the result of a selection among many possibilities, a selection with apparently no reason. He wrote (CP 6.185): "Hence, remembering that the word 'potential' means indeterminate yet capable of determination in any special case, there may be a potential aggregate of all the possibilities that are consistent with certain general conditions; and this may be such that given any collection of distinct individuals whatsoever, out of that potential aggregate there may be actualized a more multitudinous collection than the given collection. Thus the potential aggregate is, with the strictest exactitude, greater in multitude than any possible multitude of individuals. But being a potential aggregate only, it does not contain any individuals at all. It only contains general conditions which permit the determination of individuals."

Moreover, Peirce called the second category *synechism* (CP 6.103), which comes from the ancient Greek word for "continuity" (the first category was called in this context *tychism* (CP 6.102), which comes from the ancient Greek word for "chance"). The *thirdness* is often said to be the middle between the first and the second (CP 1.337). In the other category classification, the third term is also called *agapism* (CP 6.302), which comes from the Greek Christian word for "love." This is not fortuitous, because already the young Peirce [1866] had spoken of the Christian Trinity in referring to the three categories. And the same will do Peirce at the end of his life, by speaking of the triad in terms of the Triune God [1906a: 364; see CP 5.436]. Later, he will often call the first "God the creator" [CP 1.362].

It is clear that the second, the continuity is the Son (the Mediator), and the third is the Holy Spirit, the dynamical mediation between Father and Son: Love. In summary, the Father is the will and act of creation, therefore the event. The ultimate reason of the act of the creation is God's Will. On the other hand, the act of creation is in itself a germinal event in the sense that it is a call for the creature to actively participate to it. The destiny of our universe in this sense is open, and in this sense

it is an event that renew itself at each moment and at any scale: Any event is the renewal of the First Event. The Son is the Mediator and therefore relation. The Son is not only relation between God and His creatures. The Logos is also relation in itself: Any intellectual act is ultimately a relation between elements and for this reason can be cast in conditional form (Peirce 1868). The Holy Spirit is Love and therefore dynamical bond of Father and Son. Love is the elevation of any interaction because it is integration in a superior whole. In this sense, Peirce could write that "the continual increase of the embodiment of the idea-potentiality [in the Creation] is the *summum bonum*" [1906b: 388]. I think that Peirce tried to see the finite being as an analogy of this structure, and his conclusions largely fit with my analysis.

About the Author

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