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A phenomenology of identity

QBism and quantum (non-)particles

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Abstract: In order to account for the unusual objects or quasi-objects of quantum physics, one solution, explored by Décio Krause, is to perform a thorough reconstruction of logic and set theory. In this case, the question is: how to deal with the (partial) lack of criteria for individualizing and re-identifying quantum objects, when the elementary operations of counting them, and constituting sets of them, are to be performed?

Here, I advocate an alternative strategy, which consists in going below the level of logic and set theory to inquire how their categories are generated in the experience and activity of knowing subjects, and whether this mode of category generation is still relevant in the field of experimental quantum physics. This project of a “genealogy of logic” is borrowed from Husserl’s last treatise, entitled *Experience and Judgment*. It is applied to the case of quantum physics through a QBist approach to Mott’s theorization of quasi-“trajectories” in Wilson cloud chambers. It is also shown that one of the most appropriate ontologies for quantum objects or quasi-objects is to reverse the (grammatical) roles of subject and predicate, as advocated by the Japanese philosopher Nishida Kitarô in reasonable agreement with both Schrödinger’s and Krause’s approaches to the concept of “particle”.

Introduction

Décio Krause is deservedly well-known for his edification and philosophical articulation of the quasi-set theory (Krause 1992). The motivation for this remarkable work was to formulate a non-classical alternative to Zermelo-Frankel set theory that may be applied to the indiscernible particles of quantum mechanics and to the quasi-particles of quantum field theory (Krause et al. 2005). Indeed, addressing the status of *sets* of microphysical entities affords an appropriate logico-mathematical backbone to clarify ontological issues about the nature of the quantum particles.

To understand this line of research, one must remember that at least four ontological options are (more or less elegantly) compatible with quantum statistics, namely with Bose-Einstein or Fermi-Dirac statistics.

The first option is an ontology of particles devoid of individuality or self-identity: this is the so-called “received view of quantum non-individuality” (French and Krause 2006).

The second ontology associates an N-times excited quantum field with a particle-like behavior of experimental events of detection (Teller 1995, 1998; Sebens 2022).

By combining the views of non-individuality and quantum fields (the first and the second ontologies), some prominent authors of the past felt they have good reasons to doubt the very existence of particles. This is the case of Erwin Schrödinger (1952), who claimed that “(...) the particles, in the naive sense of the old days, do not exist” (See Bitbol 1996). This is also the case of Willard Van Orman Quine (1976) who considered that standard conceptions of material objects or particles are dissolved straightaway in modern physics.

The third ontology is both more conservative and less conventional than the two previous ones, since it does not even fit with Leibniz’s principle of identity of indiscernibles. This is an ontology of particles endowed with “transcendental individuality” or “haecceity” (Huggett 1999), but with no observable feature that make them distinguishable (or discernible) from one another.

The fourth ontology develops radical skepticism about the concept of monadic entities, especially monadic particles, but adopts a purely relational view instead. One may think of an ontology of pure structures (French and Ladyman 2003, Ladyman and Bigaj 2010), or an ontology of weakly, relationally, distinct particles (Saunders 1994, 2003, Muller and Saunders 2008, Rovelli 2021).

Several types of arguments (logical, physical, or metaphysical) have been presented in favor of each one of these variegated options, with the aim of showing that it alone is acceptable. But there are reasons to think that a form of ontological and representational underdetermination is bound to persist despite the strong constraints exerted by the structure of quantum physics (Van Fraassen 1991).

The problem is that only antirealist philosophers of science can unreluctantly accept a persistent (possibly permanent) ontological underdetermination. Indeed, antirealists hold that a given ontology is to be construed as a mere heuristic pattern for research, among several others. Nothing then prevents them from adopting any one of the acceptable ontologies as a mental guide whenever this is appropriate, and to use another ontology (or none) in different circumstances. By

contrast, from a realist standpoint according to which scientific theories tend to provide us with a set of literally true statements about the world (or with structures isomorphic to the world), the plurality of ontologies and theories compatible with the available data is necessarily provisional (Earman 1993). At the very least, the many available theories, ontologies, or representations, should agree on a unique ontological core (Alai 2019). Efforts have therefore been made, in realist circles, to remove the ontological underdetermination of the quantum domain, and hopefully come back to traditional ontological patterns.

One example of such effort, discussed by Arenhart and Krause (2014, 2019), was provided by Dorato and Morganti (2013). According to the latter authors, “to grant a well-defined cardinality for any plurality of items is itself the manifestation of individuality” (Arenhart and Krause 2014). So, the fact that one can ascribe sets of particles a number, more specifically a cardinal, allegedly proves that particles are endowed with “transcendental individuality”. But, as Arenhart and Krause cogently argued, this argument is flawed. Ascribing a cardinal number to a set of items does not necessarily involve the standard procedure of counting, the imposition of an order between distinguishable items while they are being counted, and the correlative generation of an *ordinal* number. It just implies that some cardinal number is globally associated to the set.

This point was illustrated qualitatively by Schrödinger (1950) while he was pondering on the meaning of quantum statistics. He noticed that, if we distribute a certain amount of money between several persons, the number of different distributions of those amounts is determined by the Bose-Einstein formula. Here, amounts of money are expressed in currency units, and *they can be valued without such units being individuals at all*. A cardinal but not an ordinal can be defined on such amounts of money; a procedure of counting and an ordinal could be defined only if the money were concretely represented by a classical set of individual coins.

But the demonstration of Arenhart and Krause (2014) is even more general. They show that “a reasonable understanding of non-individuals may be consistent with the idea of a plurality of indistinguishable items with a well-defined cardinal”. This “reasonable understanding” is formalized by the axioms of a quasi-set theory “built with the specific purpose of encoding in a formal system the idea of ... collections of non-individuals”. To sum up, what

Arenhart and Krause (2014, 2019) have shown is that “one may embrace an ontology of non-individual objects, provided one accepts that some non-classical logic should be employed”. Under the assumption of a non-classical logic and set theory, the ontology of non-individual objects recovers its plausibility, and it may even be preferred for reasons of metaphysical parsimony or lack of surplus structure.

A quasi-set approach of particle counting is a major step towards a proper understanding of quantum ontology. However, this approach remains at an excessive level of abstraction. We would like to come closer to the concrete actions and experiences through which we, cognizant subjects, come to believe that there are individualized material bodies out there, and count them as if they were a multiplicity of objects independent of us. We would also like to examine to what extent this kind of belief and procedure of counting can (or cannot) be applied to microphysical particles. And we would finally like to articulate these concrete actions and experiences to the concrete predictive use of the quantum formalism. To get thus from the abstract realm of logic and set theory, to the concrete domain of acting, experiencing and predicting, three moves have to be performed.

Our first move (section 1) is to reach the level of the cognizant subject’s lived experience (Bitbol, 2020, 2021; Bitbol & De la Tremblaye 2022). In the present case, we are interested in the experience of identification of bodies across space-time, which was accurately documented by Edmund Husserl (1973). This is all the more significant since Husserl’s study of the experiential procedure of identifying bodies is associated to a retreat from the layer of logic and predicative judgment to the layer of pre-logical perception and pre-predicative experience. Phenomenology thus provides us with a tool to inquire into the pre-logical motivation for crossing the threshold from classical logic plus classical set theory, to non-classical logic plus non-classical set theory, as Décio Krause and other authors proposed.

Our second move (section 2) amounts to go beyond the mere assimilation of individuality to tautological self-identity (Krause et al. 2020). Instead, we choose Reichenbach’s (1965) principle of “genidentity” as an ultimate criterion of individuality: a principle of research of spatio-temporal continuity for sequences of local phenomena, according to a trajectory-like pattern.

Our third move is to look for an equivalent of the two first moves at the level of quantum predictions. The connection between

phenomenology and quantum mechanics will thus be analyzed (section 3) by way of an interpretation of quantum mechanics that has a surprising amount of affinity with the phenomenological theory of perception: QBism or Quantum Bayesianism (Fuchs et al. 2014).

The two themes, identity and quantum phenomenology, are then articulated by way of a QBist approach of particle tracks in Wilson or Bubble chambers (sections 4 and 5).

1-Husserl's prelogical experience and the constitution of identity

Any claim to knowledge can be doubted, but the precondition of the act of knowing, namely lived experience, is beyond any doubt; for doubt itself is given *qua* experience. Similar remarks were made thousands of years ago, most clearly by St Augustine¹: “Suppose they say to me ‘what if you were wrong, when you declare yourself certain that you are?’ I answer: if I am wrong, I *am*; what *is* not cannot even be wrong”. Such deep realization is the basis of René Descartes’ attempt to rebuild philosophy, and it also serves as an absolute beginning to Edmund Husserl (1929/1982) in his *Cartesian Meditations*.

It is true that in situations called “normal science” by Thomas Kuhn, namely whenever general principles remain unquestioned and only special problems are at stake, returning to lived experience as the unshakable root of our quest for knowledge may seem superfluous. But when the foundations of science undergo a lasting crisis, when even our most entrenched ontological presuppositions are shaken, as it is the case in quantum physics, the *motto* can but be “back to experience”, for this is the only opportunity to make a fresh start from solid ground. No wonder the lesson Bohr (1963, p. 10) drew from quantum physics was that “Physics is to be regarded not so much as the study of something *a priori* given, but rather as the development of methods of ordering and surveying human experience”. For, after the quantum revolution, no previously accepted entity was left unchallenged. In quantum physics, as in the general problem of knowledge, a *tabula rasa* of virtually every pre-“given” concept is then needed, and a careful survey of human experience is to be performed.

¹ St Augustine, *De Civitate Dei*, XI, 26

The most radical *tabula rasa* was called “*Epoché*” and “transcendental reduction” by the founder of phenomenology. In Husserl’s approach, the two-step act of *epochè* and transcendental reduction is characterized as the gesture of (i) suspending (and withdrawing) one’s exclusive focus on the meant or intended objects, and (ii) coming back to the experience of meaning and intending (Husserl 1929/1982, p. 56). In some extreme cases (Patočka 1995), this withdrawal is complete, thus opening a field of “blank”, uninterpreted, experience. But in other cases, the withdrawal is partial, just suspending our commitment to the scientific picture of the world, without calling into question the ordinary beliefs that pertain to our “life-world” (Husserl 1936/1976, p. 167).

What is more relevant to us, is the phenomenological description of the specific *tabula rasa* which must be performed for the sake of clarifying the foundations of logic (Husserl 1938/1973). Husserl points out that, to uncover the ultimate source of the logical judgment and of its two archetypal components (subject and predicate), one must perform a “retrogression” (“*Ruckgang*” in German) towards the prelogical and even preverbal experience. “A retrogression in several stages is required in order to arrive at primal ... self-evidences, which must then form the necessary point of departure for every elucidation of the origin of the judgment” (Husserl 1938/1973, p. 22). The motivation for such retrogression towards the lower levels of the act of knowing is that “it is precisely in these lower levels that the concealed presuppositions are to be found, on the basis of which the meaning and legitimacy of the higher-level self-evidences of the logician are first and ultimately intelligible” (Husserl 1938/1973, p. 13). As soon as the said “retrogression” is performed, one can observe the budding seeds of experiential evidence on the basis of which the logical judgment, together with its underlying ontology of substances and attributes, is edified. The concept of permanent, individual, self-identical objects, presented “out there” as if they were transcendent with respect to our experience, is the (substance-like) core of this ontology.

But how do we come to believe in such objects?

To start with, Husserl points out that, as soon as the *epoché* is performed, it becomes obvious that the so-called “transcendence” of the objects of our attention arises from the immanence of the consciousness that attends to them. “It is conscious life alone wherein everything transcendent becomes constituted, as something

inseparable from consciousness” (Husserl 1929/1982 p. 62). Even if one does not adhere to dogmatic idealism, this must be granted for a simple epistemological reason. This reason is that “Every rightness comes from evidence, therefore *from our transcendental subjectivity itself*; every imaginable adequation originates as *our* verification, is *our* synthesis, has *in us* its ultimate transcendental basis” (Husserl 1929/1982 p. 59). This being granted, one must inquire into the details of the process of “constituting” objects in (and from) the flux of consciousness. And one must also inquire into the root of the conscious feeling that these objects lie beyond consciousness, in a domain that “transcends” consciousness. Since the most accurate description of this process is given in Husserl’s *Experience and Judgment* (Husserl 1938/1973), I’ll mainly follow this text. Special attention will be paid to the phenomenological analysis of object’s self-identity it contains.

What is the very first structure of immediate experience, below the “garb of ideas thrown over the world of immediate intuition and experience” by elaborate logic and science (Husserl 1938/1973 p. 44)? Such structure emerges from “the perceptive contemplation (*Betrachtung*) of the pregiven sensuous substrate” (Ibid. p. 59). It combines in one single “adumbration”: (1) the present sensory appearance of a certain “perspective”, and (2) a “horizon” of *expected* possible appearances of further perspectives. Husserl also insists that “this kind of evidence has an essential ‘one-sidedness’”. Indeed, at any single moment, each perspective shows only one side of a putative something, and nothing else. But even though no other side is visible, the still invisible is not deemed to be inexistent; instead, further sides are sketchily imagined and foreseen. Each perspective, each side, is surrounded by “... a multiform horizon of unfulfilled anticipations (which, however, are in need of fulfilment)” (Ibid. p. 61). This means that the one-sidedness of the present perspective is compensated by a blossoming of anticipated possible perspectives that are awaiting confirmation (fulfilment) in the next future.

Crucially, despite the latent multiplicity of perspectives (the present perspective together with the anticipated perspectives), this basic structure of immediate experience involves a sense of *unity*: the unity of one (sometimes several) object(s) whose many aspects are successively manifested and anticipated. Indeed, if an appearance were not considered the presentation of some object having other aspects in store that could be shown later, there would be no reason to

go beyond the present towards the expected. In immediate experience we are then bound to presuppose that a certain variety of perspectives (or aspects) pertain to one and the same object. “The naive consciousness, which, through all the perspectives, adumbrations, and so on in which the object of perception appears, is directed toward this object itself in its identity, has always in view only the result of this act: the object, which is explicated in perception as such and such.” (Ibid.) Instead of just attending to the indefinite unfolding of sensuous data, pre-predicative experience thus implies an ascription of *identity*, a unique nucleus taken as the permanent object of one’s intentional directedness. Pre-predicative experience thus associates a variety of presentations and sensuous contents whose only initial unity is established by their being recollected by the knowing *ego*, into a “noema” which imposes a pre-intellectual principle of unity of these presentations under the concept of a permanent object (Husserl 1913/2018 §97). This being granted, the sequential appearance of various perspectives is taken as the progressive disclosure of the hidden (yet partly anticipated in a former horizon of adumbrations) faces, aspects, or profiles of such object. Husserl writes that the succession of perspectives is taken as an “*explication*” of the features of one and the same object in the course of its exploration.

Let us recapitulate this phenomenological analysis of immediate (perceptive) experience, before any further elaboration. The strong association of presentations and expectations in one’s situated experience is the basic structure that gives rise to a belief in objects that can permanently afford more appearances, more information, and more opportunities to us. Such is the lived structure that supports our conviction that objects are “external” with respect to us, that they exist “in themselves” as an enduring repository of resources for us. One would not exceed a present profile by means of a ray of expectations without the motivation to discover the latent faces of some durably given and inherently existing object, namely to “explicate” *its* hitherto unseen aspects. “Every phase of perception is thus a radiating system of actual and potential intentions of anticipation” (Husserl 1938/1973 p. 87). Conversely, the implicit belief in some inherently existing objects would not occur without being borne by a constant attempt to reveal new profiles under the presupposition of their belonging to one and the same entity. In other terms, the sense of transcendence of the object is provided by the indefinite openness of the process of “explication”. It arises from the feeling that the partly explicated object always promises something additional to explore; from the

sense that accumulation of further evidence “about an object” is possible by way of a series of experiences that “are repeatable *in infinitum*” (Husserl 1938/1973 p. 87).

The lesson to be drawn from this study of the origin of our belief in objects external to us is momentous, according to Husserl. “Objectification is ... always an active achievement of the *ego*, an active believing cognizance of that of which we are aware, this something being one and continuously the same through the continuous extension of consciousness in its duration” (Husserl 1938/1973 p. 62). Husserl here points out that the “active achievement” of a pole of sameness, of an enduring self-identical entity beyond the flux of fleeting appearances, is based on a “synthesis” of such appearances by the (transcendental) *ego*. The presumption of an object’s self-identity relies on a mental act of the *ego*: the mental act of constantly aiming at the putative nucleus of an ongoing flow of changing phenomena. Only thus, by this active “retaining in grasp” of a putative “something” by an *ego*, can “it be apprehended in a simple perception as an enduring object, as one which not only is *now* but which was also the same *just before* and *will be in the next now*” (Husserl 1938/1973 p. 109). Objects are constituted by a transcendental *ego* as a consequence of the latter’s tendency to presuppose (and retain in grasp) their self-identity beyond apparent change.

We have seen that this combination of (i) “explicating”, namely developing a stream of appearances across time, and (ii) “retaining in grasp” one and the same object, is called “explicative synthesis” by Husserl. Such is precisely the experiential pre-predicative origin of the couple of categories (i) “determination” and (ii) “substrate” that a predicative judgment articulates. But, of course, the scope of the explicative synthesis, and of the predicative judgment that arises from it, is not limited to the needs of a single subject at a certain moment of her conscious life. The stabilization of the formal concepts of “substrate” and “determination”, and their articulation into a logical judgment, is in fact our central resource for elaborating a body of intersubjective knowledge. One could even say that these formal concepts, and the resulting judgments, are the condition of possibility of an intersubjectively shared science. The explicative synthesis and its crystallization in predicative judgments indeed express “the fact that, beyond the momentary situation, we aspire to create a store of knowledge which is *communicable* and usable in the future” (Husserl

1938/1973 p. 63). The explicative synthesis is what allows us to fill the gap between: (a) the immediacy of present-appearances-for-ourselves, and (b) the communication of a corpus of knowledge that holds for any future time and for anyone who will need it. “The act of perceiving and judging on the basis of perception is ... that attitude which underlies theoretical science and makes possible a confirmation with the goal of objectivity, of validity ‘once and for all’ and ‘for everyone’.” (Husserl 1938/1973 p. 65).

This phenomenological analysis has given us access to the pre-logical ground of the logic of judgments and its classical set-theoretical counterpart. We have discovered that the pre-logical ground for logic is the knowing subject’s striving to unify her lived experience in an intersubjectively communicable way, beyond the ceaseless unfolding of a variety of situated appearances. Such a quest for unity beyond and above the unstable present involves the recollection of past events, the anticipation of a continuous series of future events, and their tentative ascription to one and the same object. Can we find an equivalent of this procedure in our ordinary language and in classical Physics? And, if so, how is it disrupted in Quantum Physics?

2-Identity and trajectory

The identity of a material body through time is presupposed by the speech acts that consist of referring to it. This point is made clear by several modern theories of reference. According to Searle (1969), referring to a certain thing implies that the speaker is capable both of identifying that thing in the present moment, and of re-identifying it whenever “it” will reappear in the future. As for Kripke (1980), he considers that naming a thing amounts to accepting either (prospectively) that one will be able to recognize again and again this thing which has just been “baptized”, or (retrospectively) that one has the capacity to link the thing whose name is currently used, back to a past baptism certificate. In physics, something similar occurs.

Besides, the identity of a material body across time is presupposed by the tracking procedures of a region of space characterized by some unusual sensory or experimental feature. Such tracking procedures may involve either the oculo-motor system, or some monitoring device that operates in the same mode as the eye at microscopic or macroscopic scales. In the absence of any other criterion of identity, it

is then the connection of one region of space to another, ensured by a continuous procedure of tracking, which is taken as our only guarantee of the identity of something across time. In this latter case, one speaks of the genealogical identity, or the “genidentity” (Reichenbach 1928/1965 p. 55), of material bodies. Genidentity is clearly distinct from other modalities of identification of bodies, made possible by their possession of discriminating individual features.

Moreover, according to Reichenbach, genidentity is not just a criterion of recognition of some pre-given thing by way of its spatio-temporal track. It is a *constitutive principle* in a Kantian (and to some extent also Husserlian) sense. “When we speak of the path of an electron, we must think of the electron as a thing remaining identical with itself; that is, we must make use of the principle of genidentity as a constitutive category” (Ibid.). To understand properly this sentence of Hans Reichenbach, one should notice two points. Firstly, even though, in it, the electron is initially referred to as if it were a pre-given thing, this impression is corrected immediately afterwards. Reichenbach does not say that some electron is (or is not) a self-identical element; he rather says that *we must think of it* as self-identical across time; he thus implies that self-identity is just a presupposition by which we put ourselves in a position to attribute a sequence of phenomena to one and the same “thing” which we call an “electron”. Secondly, this preliminary act of thinking turns out to be a “coordinating principle” (a presupposed coordination of phenomena), and a “constitutive category”: one that *constitutes* an electron *qua* object beyond its manifold appearance in space-time.

In Reichenbach’s neo-Kantian approach of physics, the principles of coordination play a key role. They so to speak *define* objects of physical knowledge. They are *constitutive* of them, insofar as they prescribe the way in which phenomena must be articulated to one another so that they can indeed count as multiple manifestations of the properties of a single object.

However, Reichenbach did not retain Kant’s construal of constitutive principles *qua* perennial norms of thought. He insisted that the constitutive principles of science are relative to each step of research; they are not fixed once and for all, but are just the enduring background presuppositions of each historical phase of science (Friedman 2001). This is why scientific revolutions are not limited to better characterizations of pre-given objects; they rather imply a

“change in the concept of object” triggered by a preliminary “change of the coordinating principles” (Reichenbach 1928/1965 p. 94).

The consequences of such radical change were evaluated by Schrödinger in the context of quantum physics (Bitbol 1996, chap 4 and 5). According to Schrödinger, if two particles have all their properties in common, the only remaining possibility to distinguish them is to “genealogically” connect their present observed position to two distinct past positions, through two precise continuous trajectories. Usually, however, this does not work in the quantum domain. Indeed, the trajectories are submitted to Heisenberg’s “uncertainty principle” and therefore no pair of trajectories can be found without a mutual overlap. The standard, genidentical, constitutive principle of material particles thus falls apart. And the very “concept of object” is overturned, in agreement with Reichenbach’s lesson. This is why, in a letter to Henry Margenau of 1955, Schrödinger pointed out that “to me, giving up the path seems giving up the particle”. At the very least, giving up a spatiotemporal path of self-identification means giving up the *individual* particle.

Schrödinger’s position about the “existence” of particles is probably too clear-cut. Schrödinger indeed explicitly overlooked the fact that, in certain cases of low densities, the genidentity of particles may still be ascertained by means of their (almost) non-overlapping trajectories, thus restoring some operational sense to their individual permanent “existence”. Instead, he insisted that, however small, the non-zero probability of overlapping makes the concept of a permanent particle universally meaningless (Schrödinger 1950). And he finally declared that, such ontology of spatiotemporal continuants having been completely shattered, what is left to physicists is only a cloud of isolated detection phenomena, to be organized under non-genidentical coordinating principles. At the end of the day, Schrödinger felt entitled to assert that particles are always non-individuals and therefore (according to him) absolutely non-existent as such. But, may be, even the binary alternatives of individuality and non-individuality, existence and non-existence, are outdated in the field of quantum mechanics. May be the joint claim of (intrinsic) non-individuality and non-existence is just as unwarranted as the opposite claim of (intrinsic) individuality and existence of particles.

These claims were scrutinized in recent studies (Goyal 2019, Dieks 2020, Jantzen 2020) of a feature that underly them: persistence as a necessary but not sufficient condition of re-identifiability. Even

though Goyal starts from Schrödinger's devastating analysis, his philosophical outcome is much more nuanced. Goyal's strategy is indeed overtly operationalist. He accepts from the outset that what is given to physicists is nothing else and nothing more than a cloud of scattered detection phenomena. He accepts from the outset that the only material out of which physicists try to elaborate a conception of particles is a set of "raw data (that) consist of identical localized events". In the latter sentence, "identical" means "showing the same properties (such as mass or electric charge) in one location as in another location". Then, instead of jumping immediately to an ontological interpretation of such raw data, Goyal wonders which model is more appropriate to account for various distributions of the manifest identical localized events. Is it a model of persistence (and space-time continuity) or a model of non-persistence (and space-time discontinuity)? In other terms, should we assume that localized events are produced by persistent situated entities, or that they manifest some non-persistent distributed process? Clearly, the answer to the latter questions may vary according to the experimental context. For instance, the model of persistence will be more appropriate (yet not exclusive) in the context of a bubble chamber showing approximately aligned localized events (the tracks), whereas the model of non-persistence will be more appropriate (yet not exclusive) in the context of a two-slit experiment yielding a bi-dimensional layer of localized events (the interference pattern).

Let me emphasize at this point two innovative features of this philosophical approach. In it, ontological issues are both "en-theorized" (Fine 1996) and "en-experimentalized". What can be said about what there is (namely persistent particles or non-persistent phenomena) is relative: (i) to various theoretical models and (ii) to various experimental contexts. As a consequence, there is no absolute answer to the ontological questions "do particles exist or not?" and "are they individuals or non-individuals?" Instead, just as in the earliest analysis of experimental contextuality in quantum mechanics, the two models are shown to be "complementary" in Bohr's sense: although they are mutually exclusive, they are jointly indispensable to account for a host of weird features of quantum statistics (Englert 1996, Goyal 2019). The joint indispensability of the two models of persistence and non-persistence is not just a matter of words. It has concrete consequences, since Goyal demonstrates that "Feynman's and Dirac's symmetrization procedures arise through a synthesis of a quantum treatment of persistence and non-persistence models". These two "mutually exclusive" models are "jointly", or synthetically, needed "for accounting in detail for the quantum rules employed in the treatment of identical particles".

It then turns out that ontology is not to be understood as something we receive ready-made from “external reality”. Ontology should rather be construed as a set of structures proposed by an experimenting and theorizing subject for the sake of accounting for phenomena. This displacement of the central axis of ontological thought from a putative “external reality” to a subject who can take epistemic initiatives, strongly evokes phenomenology. But whereas Goyal’s subject is a typical pragmatist acting and thinking being, the phenomenological subject is mostly a being capable of having experiences and of initiating gestures of attention or anticipation within her lived experience. To get even closer to a phenomenological approach of quantum physics, we must now turn to QBism.

3-QBism: a physics in the first person

The word “QBism” originated as an acronym for “Quantum Bayesianism” (Caves et al. 2002 a,b; Fuchs & Schack 2013). But the proponents of QBism gradually changed their minds about the relevance of this reference to the Bayesian conception of probabilities. Aren’t there multiple versions of Bayesianism; do we not distinguish in particular an objectivist version from a subjectivist version of Bayesianism? To manifest a decision in favor of the latter, it was first proposed to make the “B” of QBism the initial of “Bettabilityism”: the thesis that quantum physics is equivalent to a betting system. But as this word in “ism” is too heavy, a half-serious (and only transient) suggestion was to consider that the letter B is the initial of Bruno, for Bruno De Finetti (Fuchs 2016).

After all, it is on the audacity of Bruno De Finetti (2008) that the audacity of the authors of QBism is based: if we want to make quantum theory intelligible, they claim, we must transform not only our interpretation of the theoretical symbols (by identifying them with pure probabilistic valuations), but also our conception of what probabilities do, and our idea of what physics is. In quantum theory, these transformations are stated as follows: quantum “states” look like Bayesian personalistic probabilities associated to bets (Fuchs 2010). One could even say that quantum states are nothing beyond such personal probabilistic estimates. Quantum “states” do not denote the properties of some microscopic “system” (Fuchs 2015), they do not represent waves, and even less do they “describe” particles; they express our propensity to bet about an experimental outcome.

This position represents a complete overturn of our views about physics, and science in general, similar to Kant’s “Copernican

revolution”. According to the standard view, a science must first offer a description of *what there is*, before predicting *what will be seen*, and before becoming interested in the very *point of view from which everything is seen*. The reverse is explicitly assumed in QBism. QBism prescribes that physics wonder about its own departure point in the lived life of physicists. QBism also prescribes that we suspend (at least temporarily) questions about what there is beyond the visible, in the post-physical or meta-physical margins of the inquiry, and rather focus on the visible things that can be anticipated probabilistically.

But what are the visible things that turn out to be primarily relevant to physics? For Bohr and his successors, these are the dials of measuring devices, describable in everyday language supplemented by the concepts of classical physics. For QBists, instead, “seeing” is more immediate and more intimate; it directly concerns the lived experience of subjects, prior to any assignment of existence to macroscopic objects such as measuring devices. “In QBism the only phenomenon accessible to Alice which she does not model with quantum mechanics is her own direct internal awareness of her own private experience. This (and only this) plays the role of the ‘classical objects’ of Landau and Lifshitz for Alice (and only for Alice). Her awareness of her past experience forms the basis for the beliefs on which her state assignments rest. And her probability assignments express her expectations for her future experience” (Fuchs et al. 2014).

All central concepts of physics are reconstructed by QBists out of the elementary material of present lived experience. Indeed, ascribing *present experience* the role of a radical origin of knowledge is crucial to the QBist dissolution of enigmas such as EPR correlations (Fuchs et al. 2014) or Wigner’s friend paradox (De Brota et al. 2020). As a consequence, just as in Kant’s and Husserl’s doctrines of the “constitution of objectivity”, the traditional hierarchy of knowledge is reversed in QBism (De la Tremblaye and Bitbol 2022). The object to be known is no longer an entity given in advance, and subsequently studied by the knowing subject. The object is no longer posited before the subject, being thereby considered as what arouses her experience. Instead, it is the experience of the knowing subject which decides what counts as an object. Accordingly, a QBist thinker should not start from a preliminary notion of “system”², to then assign probabilities to

² Although QBists often speak, for the sake of communication, as if such “physical systems” were already given out there, ready to be probed.

the values of observables measured “on it”. On the contrary, she should come to speak of a “system” only if the order of the probabilities that she evaluates is in conformity with that which she would expect from an entity of this type. “Whereas the usual approach in physics would presuppose an objective world and explain the different perspectives by ‘carving out’ parts of it to serve as the perceiving subjects, QBism begins with a fundamental plurality of perspectives and seeks to derive some notion of objective concepts from them” (Pienaar 2020). Even more directly perhaps, “any user’s own experience constitutes all of the raw material out of which she constructs her world” (Fuchs et al. 2014). QBism goes so far as to bring back all the epistemological dualities, that of subject and world, that of observers and environment, or that of agents and targets of their actions, to the unique field of lived experience wherein they take shape. “In QBism, an element of reality is an experience, which contains as a fundamental internal structure a pairing of an experiencing subject with an experienced object” (Pienaar 2020). This is an accomplished form of Kant’s “Copernican revolution”, in which appearing is not only the starting point of knowledge, but the very fabric of what we call “reality”; and in which lived experience is not a place where objects allegedly external to it are given, but rather the original ground from which the subject-object duality arises.

The final step of the probabilistic purification of quantum theory by QBism consists in realizing that “the things which can be seen” and which are foreseen (the quantum phenomena), are not obtained passively, but actively. QBism marks this recognition by replacing the word “observer” with the word “agent”. The agent does not just collect the information. She pre-orders information through the design of her measuring device. And she arouses information (she “*creates*” it) by the effective implementation of such device. In other terms, a phenomenon is *co-generated* by the agent equipped with some measuring device, and by the environment she explores. Thus, each experiment is a creative act. Each experiment gives birth to a pure novelty that manifests *qua* lived experience. “A measurement does not, as the term unfortunately suggests, reveal a pre-existing state of affairs. It is an action on the world by an agent that results in the creation of an outcome — a new *experience* for that agent” (Fuchs et al. 2014).

To sum up, QBists hold that the proper foundation of quantum physics is the agent capable of experience. This view looks like a

combination of pragmatism and phenomenology, or at least (to stick to the framework of William James philosophy) a combination of pragmatism and radical empiricism. But then, how do QBists carry out the task they have assigned to themselves, namely deriving objective concepts from agent's perspectives? Even though such procedure is not described very explicitly in the QBist literature, several features suggest that it might be similar to that of the phenomenological constitution of objects. Let me first remind that, according to QBism, quantum knowledge associates (i) a system of probabilistic expectations of potential experimental outcomes, expressed by a state vector and an observable, with (ii) a prescription to use actual experimental outcomes as a basis for redefining probabilistic expectations (such prescription amounts to using the "projection postulate", but without the reifying undertones that usually come with it). This couple of operations comes remarkably close to Husserl's phenomenological theory of perception, with its horizons of expectations that can be fulfilled or disappointed by "intuitive contents" made of sensory experience, and that are then continuously redefined according to whether they are fulfilled or disappointed (De la Tremblay 2020).

This being granted, the QBist procedure for constituting spatio-temporally persistent objects is bound to follow the additional rules indicated by Husserl (1973). In Husserl's procedure, the expectation pattern for future appearances is informed: (i) by a synthesis of past and present appearances, and (ii) by the tacit presupposition that they do and will concern one and the same enduring object. Such twofold determination of the subject's expectations is tantamount to "retaining (a self-similar enduring object) in grasp" beyond the changing past and future experiences. In the QBist interpretation of quantum physics, the contribution of the past is represented by taking into account earlier measurements of generic features such as mass and charge, but also by acknowledging the latest measurements of spatial, kinematical or any other coordinates. This allows the QBist agent to write down an initial quantum state that is likely to express the best basis for the probabilistic valuation of future measurements of those coordinates.

Now, is there an equivalent of the "retaining in grasp" of one and the same enduring object in the QBist system of probabilistic valuations for *future* measurements? The answer to this question is positive; and it is not too difficult to find such equivalent.

To calculate the probability of a future experimental outcome through the Born rule, any quantum physicist (and the QBist as well) performs the inner product of the eigenstate corresponding to this outcome by a certain quantum state. But which quantum state? Not the initial quantum state that immediately accounts for a set of past measurements, but another quantum state derived from the former one by having an evolution operator acting on it. This evolution operator is usually derived from the Schrödinger equation, and it crucially involves a Hamiltonian operator. The Hamiltonian operator includes a set of variables that express both the generic features, the (putative) spatio-temporal location, and the physical environment of a certain (putative) classical system of enduring self-identical particles. The latter feature of the procedure of probability valuation is highly significant. It means that a quantum agent builds her expectations *under the open presupposition* of the self-identity and persistence of some “physical system” of particulate entities whose interaction with her experimental device is supposed to generate the relevant future phenomena. In the same way as the phenomenological subject, the QBist agent thereby projects a “horizon” of anticipations which is conditioned by her “retaining in grasp” some alleged enduring entity. In the same way as the expectations of the phenomenological subject, the expectations that the QBist agent formulates under the presupposition of the persistence of a “system” of bodily entities can either be fulfilled or disappointed. In the same way as in phenomenology, the enduring bodily entities are not pre-given items liable to *description*, but rather background assumptions that determine a structure of *predictions*. However, unlike the phenomenological subject, the QBist agent can make use of unconventional resources. The first resource is that the background (corpuscularian) presuppositions are not rigidly connected with the predictions, but only probabilistically, through a mathematical device involving a formalism of state vectors articulated with the Born rule. The second resource is that, in case the standard, unformal, semi-classical, unprobabilistic, expectations a QBist agent may formulate under the hypothesis of the persistence of some entity, are systematically disappointed, she is free to use the alternative presupposition (or model) of non-persistence, and combine it with the former “complementary” presupposition. For only combinations of the models of persistence and non-persistence can make the standard (unformal, semi-classical) expectations fit the probabilistic expectations afforded by the quantum formalism.

An illustration of this procedure will now be given in the next section. It concerns the wave-mechanical account of tracks in a cloud chamber by Nevil Mott. Just as the QBist account, this one *does not involve the description* of a particle trajectory, but a method of probabilistic *prediction* of trajectory-like alignments of ionized droplets, under the *open presupposition* of the persistence of such particle. And just as in our reading of the QBist procedure, this presupposition for the sake of prediction is encoded in “the particle’s Hamiltonian”.

4-Particle-track prediction without pre-given particles³

Nevill Mott’s paper entitled “The wave mechanics of α -ray tracks” (Mott 1929), is deservedly well-known as a seminal work about certain fundamental aspects of the quantum theory of measurement. But here, we will downplay the relevance of Mott’s study for the measurement problem, and rather insist on its implications for the issue of the emergence of phenomena interpretable as manifestations of self-identical particles (Figari & Teta 2013, Ballesteros et al. 2021).

As a preliminary, we must notice some differences in the way Mott and Heisenberg (1930) accounted for the phenomenon of tracks in Wilson’s cloud chambers exposed to radiation. Mott was clearly attempting to promote a purely wave-mechanical account of this phenomenon. Instead, while he mostly relied on Mott’s calculations, Heisenberg tried to enact Bohr’s concept of “complementarity”. Heisenberg indeed replaced the virtually exclusive wave-mechanical bias of Mott’s paper, by an alternation of wave and particle representations. He thus substantiated the common-sense interpretation of trails of water droplets in cloud chambers as the manifestation of particle trajectories. Under this interpretation, high-energy particles impose local ionization to water molecules in the cloud chamber along their path, and those ionized molecules in turn trigger condensation of other water molecules around them, thus forming a visible trail of water droplets.

Let us begin with Mott. His starting point was the interpretation of Schrödinger’s wave mechanics expounded a few weeks earlier by Charles Galton Darwin (1929). But Mott made Darwin’s ideas more

³ This section is partly derived from the (unpublished) text of a talk delivered at the workshop “History of Radioactivity”, organized by C. Blondel et P. Radvanyi as a satellite meeting of the annual conference of the French Society of Physics held in Paris, in 1997.

concise, more operational, and also perhaps less metaphysical. The initial motivation of both Darwin's and Mott's papers was Gamow's (1928) theory of radioactive disintegration, which had also been formulated independently by Gurney and Condon (1928). In this theory, the emission of α -rays was explained wave-mechanically by means of the concept of potential-barrier penetration. The amplitude of the wave function decreases exponentially with the thickness of the potential barrier; but it has a non-zero value outside, and this accounts for the non-zero probability of the leaking of α -rays out of the nucleus. Now, the problem is that, as soon as they have emerged, the α -rays appear to have essentially corpuscle-like properties, for they give rise to tracks in cloud chambers. Charles Galton Darwin's project was then to restore a certain conceptual homogeneity between the explanation of the radioactive emission (which is based on pure wave mechanics) and the account of detection (which must apparently involve corpuscularian categories). He wished to make sense of the α -ray tracks without resorting to the process that consists in imagining that each time an observation is made, "the wave [turns] into a particle and then back again [into a wave]" (Darwin 1929). He then wanted "to show how a discussion *only* involving the wave function ψ would give spontaneously the results which simple intuition would suggest could only be due to particles" (Ibid.). As for Mott (1929), he also insisted that "wave mechanics *unaided* ought to be able to predict the possible results of any observation that we could make on a system".

How could Darwin and Mott achieve this remarkable result? They did so first of all by ascribing a single multidimensional wave-function to the global system made of the α -particle *plus every ionizable atom in the cloud chamber*. "Before the very first collision, (the wave function) can be represented as the product of a spherical wave for the α particle, by a set of more or less stationary waves for the atoms. ... [The] first collision changes this product into a function in which the two types of coordinates are inextricably mixed" (Darwin 1929). The latter sentence is an early statement of what we now call the *entanglement* of wave functions after Schrödinger (1935). Darwin (1929) further insisted that "the trouble ... in the quantum theory has only arisen through attempts to work with an incomplete ψ ", namely a ψ -function that does not include relevant elements of the measuring device. As for Mott (1929), he noticed that "... we are really dealing with wave functions in the multi-space formed by the coordinates both of the α -particle and of every atom in the Wilson chamber". But what

does this multidimensional wave-function represent? Can it be considered as a mathematical picture of some real process out there? By no means. According to Darwin and Mott, the quantum mechanical account, including in cases where this account uses entangled wave functions, does not provide the slightest element of *description* of the putative processes underlying the α -ray track phenomenon; it only enables us “to *predict* the possible results of any observation”. In other terms, “interpreting the wave function should give us simply the *probability* that such and such an atom is ionized”, and the probability that a series of such ionizations generate a sequence of more or less aligned droplets in the cloud chamber.

This way of using the wave function is in perfect agreement with Schrödinger’s late conception of his wave mechanics. In a lecture given in the early 1950’s, Schrödinger (1995 p. 50) insisted, almost in the same terms as Mott’s, that what he called the “interpretation” of a wave function is nothing more and nothing less than the (probabilistic) connection between the continuously changing overall wave functions and the observed outcomes of a measurement. This purely probabilistic interpretation of the wave function also fits neatly with QBism, which will allow us (in the next section) to base a QBist approach of particle’s self-identity on Mott’s wave-mechanical theory of α -ray tracks.

Accordingly, Mott and Darwin insisted that, in a quantum approach of the α -ray tracks, the multidimensional wave-mechanical account must be pushed as far as possible, and that any reference to corpuscular or discontinuous pictures must be delayed as much as possible. This method is fully homogeneous and coherent, insofar as it consists in developing the continuous predictive formalism until the stage where a probabilistic prediction is required, rather than mixing up continuous predictive elements with unwarranted discontinuous descriptive stories. Mott (1929) thus recommended that “until this final [probabilistic] interpretation is made, no mention should be made of the α -ray being a particle at all”. As for Darwin, he took this delay as the pivotal concept of his interpretation of quantum mechanics, and as a sort of *leitmotiv*. I take it that the verb “to postpone” is the keyword in Darwin’s paper. Darwin’s major aim was indeed to show “how it is possible to *postpone* speaking of particles”; for according to him, “there is no need to invoke particle-like properties in the unobserved parts of any occurrence, since the wave function ψ will give all the necessary effects”. Each entangled wave function can be

read as a disjunction of conditional statements, relating one ionization to a series of other expected ionizations approximately located on the straight line joining the radioactive nucleus and the first ionization. While the probability of the first ionization is evenly distributed, the conditional probability of obtaining an approximately straight track uniting the radioactive nucleus and this first ionization is very high. However, here again, says Darwin, “The decision as to the actual track can be postponed until the wave reaches the uncovered part where the observations are made”. Later on in his paper, Darwin went even further, in suggesting that it is only at the level of the brain that we are really compelled to stop the chain of entanglements, and that it is our *consciousness* that so to speak cuts sections of the overall wave-function when it becomes aware of the outcome of observations. He thus anticipated later (sometimes controversial) views of the measurement problem such as Von Neumann’s, London’s and Bauer’s, or Wigner’s. But this urge to *explain* how it is that *we finally see* a single track, in spite of the multiple-track structure of the relevant overall wave function, is a clear sign that Darwin was still tempted with ascribing a partly descriptive status to wave mechanics, rather than a purely predictive one. Far cry from Darwin, Mott avoided such speculations straightaway; he contented himself with having proved that *the probability of observing two (or more) ionized atoms in the cloud chamber vanishes unless the line that joins them passes near the radioactive atom.*

As I mentioned earlier, the interpretative strategy used by Heisenberg (1930) was quite different. Unlike Mott and Darwin (and owing to the influence Bohr exerted on him), Heisenberg had no reluctance to jump from the corpuscle representation to the wave representation and back again whenever it appeared convenient to do so. According to him, nothing prevents one from using the corpuscular picture (though submitted to the uncertainty relations) when the tracks in Wilson cloud chambers have to be accounted for quantum mechanically, notwithstanding the fact that a wave picture is more convenient to explain the radioactive emission. In the same spirit, he considered that including the α -particle and the ionizable hydrogen atoms of the cloud chamber within the same compound system, or taking the α -particle as the only system and the ionizable atoms as part of the observation device, is a matter of free choice. A cut has to be introduced somewhere between the system and the observation device, but, says Heisenberg after Bohr, the location of this cut is almost arbitrary; it only depends on pragmatic considerations.

Accordingly, Heisenberg did his best to show that, in the problem of α -ray tracks, the method of successive reductions of a wave packet (in which the α -particle is the system) gives exactly the same predictions as the method of entangled wave functions (in which the system includes not only the α -particle but also the ionizable atoms in the cloud chamber).

Now, what are we to think about this difference between Heisenberg on the one side and Mott and Darwin on the other? Heisenberg was certainly right to point out the strict predictive equivalence between wave packet reductions and entangled wave-functions. However, the two methods are not equivalent from a conceptual standpoint. The first method (favored by Heisenberg) is quite widespread, but it prevents us from appreciating the purely probabilistic status of the wave functions and state vectors of quantum mechanics. Instead, Darwin's and Mott's method is less popular, but it has the merit of putting probabilities to the fore, thereby connecting immediately with the remarkable capacity of QBism to dry up the source of the so-called "quantum paradoxes". Besides, the method of successive wave-packet reductions is usually much simpler but more misleading. It consists in using the information afforded by each point-like observation to extract a new wave function for the α -particle alone, out of the compound wave function of the larger system consisting of the α -particle plus a certain ionized atom. But one usually forgets this process; one usually forgets that successive reductions are by no means *changes* of the initial wave function, but rather *redefinitions* of it for practical purposes. As a consequence of this forgetfulness, the discontinuous evolution of the wave function is mistaken for a sort of *descriptive* account of the real process that gives rise to the track, and this arouses spurious questions about the "physical mechanism" of the (allegedly physical) wave packet reductions. By contrast, the method of the entangled wave-functions has the merit of permanently maintaining a clear distinction between the continuous (wave-like) predictive model, and the series of predicted particle-like discontinuous phenomena. The only question which arises in this latter method concerns not the discontinuous collapse of the wave function, but the progressive shift from a wave-like to a classical probability theory when the system encompassed within the global wave-function grows bigger and bigger. In other words, the question here is that of a progressive loss of interference terms in the probabilistic formalism. As we now know, a plausible answer to *that* question, but *not directly* to the question about wave-

function collapse, has been provided by decoherence theories. In terms borrowed from Bub & Pitowsky (2007), while decoherence solves the “small” measurement problem of probabilistic transition, the “big” measurement problem of how a superposed “state” collapses to some well-defined eigenstate of an observable, is a “pseudo-problem”.

Despite some remarkable exceptions (Bell 1987 p. 119), Mott’s approach of the track and self-identity of particles have usually been overlooked. It has also triggered many misunderstandings (Broyles 1993, Marolf 1994), which reveal how difficult it is to recognize the exclusively probabilistic status of the quantum formalism. Broyles and Marolf both wish to explain the track phenomenon in terms of wave mechanics, or pure unitary quantum mechanics; and they both acknowledge Mott’s pioneering work in this field. However, they also claim that something is missing in Mott’s approach. Broyles, for instance, considers that, in Mott’s approach, “the questions still remain how a wave function with a broad extent *collapses* to a track, and what *causes* the probability distribution of observed tracks to be proportional to the magnitude squared of the incident wave”. Yet, as it should be clear by now, Mott did not “fail” to answer these questions, for the simple reason that he did not treat them as questions at all. The first question, about the collapse, was made irrelevant by Mott’s choice to process an entangled wave function throughout, and by his using such overall wave function as a purely *predictive* device (for calculating the *probabilities* of the events), rather than a *descriptive* device (for giving a symbolic counterpart of the discontinuous events themselves). As for the second question, about the *reason why* there is a relationship between ψ -waves and probabilities, it did not even arise in Mott’s approach, for, according to the latter, there is not a *real wave* on the one side, and a probability assessment that has to be derived from it on the other side; there is a wave *function* whose *only role* is to afford probabilities, a wave function which is probabilistic from the outset. Broyles and Marolf are thus somehow closer to Darwin than to Mott. Indeed, Darwin was still trying to *explain* the selection of one term among many, within the overall superposed wave function, by a procedure that has been later compared with decoherence (Figari and Teta 2013). Instead, Mott tended to dissolve the measurement problem altogether by means of a purely probabilistic interpretation of the wave function.

5-Track-like predictions and presumed self-identity

I will now propose a reading of Mott's account of tracks in cloud chambers which entirely dispenses with the *two* concepts of extended wave and persistent particle. This reading combines the deeply first-personal probabilistic interpretation of quantum mechanics proposed by QBism with the time-oriented analysis of perception developed by phenomenology. It thereby offers an agent-centered conception of self-identity; a conception based on the structure of the agent's expectations rather than on some intrinsic feature of pre-given particles.

Along with this reading, the spherical Ψ -wave that emanates from the radioactive material does not "describe" the α -rays in any way. It rather expresses the agent's anticipation of future phenomena, based on knowledge of her past choices and past observations. The spatial extension of the Ψ -wave thus expresses nothing else than the spatial distribution *of the agent's expectation of potential phenomena*; in other (Kantian) terms, the spatial extension of the Ψ -wave is the *a priori* form of the agent's experimental future-oriented receptivity. As for the local amplitude of the Ψ -wave, it expresses the intensity of the agent's predisposition to bet in favor of the appearance of a detection phenomenon at the corresponding point, or in the corresponding volume. It is crucial to this reading that not only waves, but also particles, are *not* said to be *described* by the Ψ -functions.

But then, what is the connection between this way of understanding the quantum formalism and the observed tracks, namely the observed particle-like appearances of water droplets trails in a cloud chamber? Since this connection is *not* one of *description*, it must be one of *presupposition*. Even though a Ψ -function does not describe the features of a "real" particle, its variables are the coordinates of a *model-system* previously composed (*in the agent's mind*) of a model-particle plus a model-set of ionizable atoms. Inserting these coordinates in the argument of the Ψ -function associated with the cloud chamber, is a way to *mentally presuppose* that a persistent particle may ionize atoms there. And submitting this Ψ -function to evolution through a Schrödinger's equation whose Hamiltonian depends on particles and fields variables, is a way to *mentally presuppose* that this particle moves in a certain energy (or potential) landscape. Then, the probabilities calculated by applying the Born rule to this time-evolved Ψ -function show the distribution of events that

can be *expected* when this highly elaborated *presupposition* is made. At the end of the process, the observed phenomena are compared to such expectations, thus enabling one to test the presupposition. But what is remarkable in the quantum paradigm is that, since the agent's expectations of particle-like behavior of finite sequences of phenomena are purely probabilistic, testing them in various experimental contexts may yield a continuous scale of agreement ranging from strict agreement to complete disagreement. Even in a particle-presupposition-friendly experimental context like the cloud chamber, the outcome is *not entirely* in favor of the persistent particle model, since the sequence of ionized atoms and droplets is discontinuous, and these droplets are not perfectly aligned. This is why quantum phenomena can never be anticipated under the presupposition of a single model (such as the model of persistent particles), but only under the presupposition of a mix of mutually exclusive models (such as Goyal's models of persistence and non-persistence).

Mott's wave-mechanical approach of the α -ray tracks in a cloud chamber is perfectly compatible with this purely presuppositional, rather than descriptive, status of the model of persistent particles. In this approach, each ionized atom, and each droplet, of the track is by no means treated as a direct manifestation of the sudden transformation of a wave into a particle, as it would be in Heisenberg's multiple collapse approach. Instead, it is treated as the actualization of one of the possible phenomena that are probabilistically predicted by way of a Ψ -function whose structure and evolution convey the (*mental*) presupposition of a model of persistent particles. By extrapolation, a sequence of ionized atoms, and droplets, loosely distributed along a straight line is not treated as the direct manifestation of a "real" particle's trajectory. Instead, it is treated as the actualization of a coherent set of consecutive phenomena, probabilistically predicted by way of a Ψ -function whose structure and evolution convey the (*mental*) *presupposition* of a combination of kinematical *models* (persistence and non-persistence, with a dominance of the persistence model). In every case, the model of persistent particles remains in the background (or in the backstage) of the probabilistic formalism of quantum mechanics, rather than being thrown onto the stage of some objective process which the theory allegedly represents; and it is denied any exclusivity, since it is combined, though to a small extent, with the model of non-persistence. As we have seen earlier, a consequence of the background

presupposition of the predominance of a model of persistent particles is that the probability of observing a series of ionized atoms (and droplets) in the cloud chamber vanishes unless they are approximately aligned. But this global prediction, that bears on the whole track rather than on each of its points, does not require the assumption that a particle has materialized at each point by way of a series of real wave-packet reductions.

This is what makes Mott's purely probabilistic approach of the α -ray tracks, pushed to its ultimate consequences by the QBist interpretation of quantum mechanics, so closely akin to the phenomenological conception of self-identity. Here, as in Husserl's analysis, self-identity is not found ready-made in nature. It is *supposed in advance*, and actively achieved, by the (highly elaborated) mental expectations of a subject, and by the coordinated experimental interventions of an agent. Here, as in Husserl's analysis, achieving the self-identification of a putative entity requires the *synthesis* of a succession of appearances under its concept. In the phenomenological theory of perception, the appearances to be synthesized are the aspects or profiles tentatively ascribed to an extended body. Instead, in microphysics, the appearances to be synthesized are the ionized atoms and droplets (or bubbles) found in a cloud (or bubble) chamber and tentatively ascribed to a particle. Here, as in Husserl's analysis, one tends to constantly aim at a single object for the sake of predicting "its" next manifestations. In the phenomenological theory of perception, such putative object is (mentally) "retained in grasp" while future aspects or profiles are anticipated in the horizon of present aspects of profiles, and later pop up one after another in experience. In microphysics, the (mental) model of some persistent particle is maintained as a component of each scientist's background presuppositions. This mental model determines to a certain extent the probabilistic anticipations of future ionized atoms (and droplets), and it is repeatedly tested by the appearance of new ionized atoms (and droplets). In both cases, once again, the same process of "explicative synthesis" under the background presupposition of a self-identical entity, is performed as the succession of phenomena (profiles or droplets) gradually unfolds.

To sum up, in microphysics as in phenomenology, self-identity arises as the focus of a mental act of presupposition, synthesis, and explication of a single object-concept maintained throughout the development of what is tentatively taken for "its" phenomenal

manifestations. Self-identity is mentally posited (or withdrawn), rather than found ready-made out there.

6-On suspending the presupposition of self-identity

Since the model of self-identical and persistent particles looks so contrived, since it is based more on our intellectual inheritance than on a fully convincing body of evidence, is it possible to dispense with it altogether? Arenhart and Krause (2014, 2019) remind us that an alternative view has been available for some time now: the quantum field theory (QFT), with its Fock space formalism. Redhead and Teller (1992) thus “propose a shift to the Fock space formalism, in which one keeps only the *number* of particles in each situation, but no labels or counting would remain”. Among other significant features, the Fock space formalism involves creation and annihilation operators. However, such “creations” and “annihilations” do not concern persistent self-identical particles, but rather abstract units (*quanta*) to be added to (or subtracted from) the overall number of shadowy quasi-particle-like entities.

How does the Fock space formalism work? What are its similarities and differences with the formalism of standard quantum mechanics (SQM)? Overall, the Fock space formalism works exactly in the same way as the formalism of standard quantum mechanics, namely as a structured system of probabilistic anticipations, or tendencies to bet, about phenomena. It bears another crucial similarity with standard quantum mechanics: the dependence of those phenomena to the experimental devices in the context of which they are observed; in short, *their contextuality*. The concept of quantum field is indeed extrapolated from a classical concept of field through the imposition of relations of commutation (or anti-commutation) to certain couples of field variables, which thereby become field “observables”. And these relations of commutation (or anti-commutation) translate the mutual exclusion of experimental contexts into a mutual exclusion of the values measured in such contexts. But besides these similarities, there are also differences that are highly significant for the issue of self-identity. In QFT, the probabilistic anticipations (and tendencies to bet) are based on the presupposition of a field that can be excited a whole number of times, whereas in SQM, they are based on the usual presupposition of an ensemble of self-identical (yet indiscernible) particles bearing various properties. The state vector in Fock space of QFT can thus be understood (in the spirit of QBism) as a bet on the

number of detections to come, not as a bet on the number or properties of allegedly existent/(more or less) persistent particles. Unlike the literal existence of particles, the number of detections is highly contextual, as illustrated by the Unruh effect (Crispino et al. 2008). And unlike the number of particles which is pregiven, the number of detections is predicted by means of state vectors which can be *superpositions* of eigenstates corresponding to several eigenvalues of the observable “Number” (Dunningham et al. 2011). In such situation, the formal concept of particle is shattered (since it has lost the last remnants of its self-identity), and the word “particle” itself thus becomes little more than some verbal wreckage of an archaic conceptual system. As Teller (1995, p. 105) pointed out, “states [in Fock space] simply characterize propensities for what will be manifested with what probability under various activating conditions. Among the items for which there can be propensities for manifestation is the occurrence of various numbers of *quanta*...”.

Accordingly, both concepts of “quantum state” and “observable” acquire a new meaning in quantum field theory. In QFT, a quantum state is a predictive structure derived from a presupposed quantum field model, with its potentially detectable excitations (*quanta*), instead of being a predictive structure derived from a presupposed particle model, with its potentially detectable properties. In QFT, a quantum state serves to evaluate the probabilities of events that are said to co-emerge from an interaction between the presupposed quantum field and a device framed under the presupposition that its number of excitations can be measured. It no longer serves to evaluate the probabilities of events that are said to co-emerge from an interaction between the presupposed particles and a device framed under the presupposition that their “properties” can be measured. Also, in quantum field theory, a certain observable denotes the set of possible natural integers that can arise under appropriate detection and counting conditions. In more familiar terms, the observable “Number” denotes a potential number of future detections expressing the excitations (*quanta*) of a presupposed quantum field. By contrast, under the standard presupposition of a particle model, an observable denotes a set of possible values (be they real numbers or integers) that can arise under conditions that are deemed to allow the measurement of particles’ properties.

From SQM to QFT, a complete turnabout of our ontological commitment has then occurred. What (in classical theories and SQM)

was presupposed as substrates of properties, namely (the discernible or indiscernible) “particles”, has acquired the status of a collective quantitative property of specific quantum fields in QFT. From the standpoint of the history of philosophy, this ontological turnabout amounts to a shift from Aristotle’s metaphysics to a neo-Platonic view. The Aristotelian scheme of a plurality (individual) substances endowed with their essential or accidental properties is indeed overturned in favor of the neo-Platonic scheme of a unique universal instantiated several times (Alvarado 2020). In the first case, individual substances are taken as the permanently existing entities that can bear variable properties, whereas in the second case what truly exists is a set of immutable universals (or “ideas”, or generic features) whose concretions in the manifest world take the form of individuals that “participate” in it. The quantum field theoretical scheme is even radicalized with respect to its neo-Platonic counterpart, since the instantiations (the *quanta*) of the underlying universal (the field) are a far cry from being engaged in a process of individualization.

In the same way as the Mott-QBist analysis of identity through space-time is closely akin to Husserl’s phenomenological analysis of perceptive identity-ascription, the QFT inverted ontological scheme has an experiential counterpart. But this experiential counterpart was upheld by somehow marginal actors in the field of phenomenology: mostly Max Scheler (1923), Nishida Kitarô, respectively a German philosopher and a Japanese philosopher of the twentieth century.

In Scheler’s phenomenological approach, the question to be resolved bears on how the feeling and concept of one’s individual consciousness crystallizes within “(...) the background of an omniencompassing and ever more vague consciousness in which our own existence and the experience of others are in principle presented as included together”. To understand how the sense of individuality emerges out of a generic experiential background, Scheler provides us with a pictorial view of the most likely process of this emergence: “(...) What is given is a stream of immediate experience, undifferentiated into ‘mine’ and ‘thine’, which effectively contains our own experience and that of others in a state of indistinction and reciprocal fusion. Within this flow are gradually formed ever more stable vortices, which slowly draw additional elements into their circle and are thereby identified successively and very gradually with distinct individuals”. Vortices in an oceanic flow is Scheler’s metaphorical account of the process of formation of individuals selves

out of a universal substrate which is nothing else than “(undifferentiated) immediate experience”.

As for Nishida Kitarô, he bases his philosophy on the phenomenology of Zen meditative states which yield pre-personal forms of consciousness. And he then translates this phenomenological background into a new logic (the “logic of place”) that reverts the Aristotelian hierarchy of substance and predicate, by giving the predicate an ontological priority over the substance. As noticed by Masao (1995), “The logic of place is a predicative logic in the radical sense, not a logic of the grammatical subject. ... It is not a logic about the act of seeing or of knowing nor is it a logic about that which is seen and known objectively in terms of the grammatical subject; rather, it is a logic of “place,” which is prior to, and the source of, both seeing and knowing and that which is seen and known. It is a subjective or existential logic prior to the opposition of subject and object”. From such anonymous “place”, namely from such a blank experience prior to space-time coordination and to the subject-object distinction, individuals may nucleate, and be thrown in space-time. From the pure predicate of being, (individual) beings may arise.

To be sure, this parallel between the ontological turnabout of quantum field theory and the non-aristotelian phenomeno-Logic of Scheler and Nishida is *prima facie* little more than an analogy. By contrast, the comparison between the QBist probabilistic approach of quantum mechanics and Husserl’s phenomenological description of perception is not merely analogical. Indeed, the pattern of (quantum) probabilistic predictions of experimental phenomena turns out to be an extension and an amplification of the (phenomenological) pattern of expectations of object’s profiles that continuously unfold in perception. Taken together, anticipatory perception and formalized rules of betting represent two layers of a single cognitive operation of minimization of surprise (Friston 2013): a biological/implicit layer and a rational/scientific layer.

Yet, the phenomenology of pre-individual experience may have been not only an illustrative analogy, but also a productive analogy: a historical source of inspiration for the ontological turnabout of quantum field theory. Indeed, it is striking that the earliest ancestor of quantum field theory, namely the wave mechanical theory of quantum gases (Schrödinger 1926), was indirectly suggested to Schrödinger by his almost contemporary reflection about the universal, pre-individual

consciousness which is the central axis of the Indian *Upanishads* (Schrödinger 2008).

Conclusion

In this paper, we have pursued a phenomenological inquiry about how the categories of persistent spatiotemporal continuants endowed with properties are generated within the experience and activity of knowing subjects. This inquiry was based to Husserl's project of a thorough "genealogy of logic (and set theory)". We have shown that, even though such phenomenological process of generation of standard ontological categories was successfully extrapolated in the formalism of classical physics, it fails to a very large extent in quantum physics.

The crucial point, here, is expressed by the qualification "to a very large extent". If the generation of standard ontological categories had failed *entirely* in the quantum domain, it would have been tempting to interpret this failure along with a "realist" philosophy of science. Would a *complete* failure not have been a proof that the standard entities of classical physics "do not exist", while other non-standard entities (say fields) "exist" in their stead?

By contrast, a *partial* failure of the phenomenological genealogy of logic and set theory tell us a very different story. It suggests that any ontology that may underly logic and set theory is nothing else than a mental scheme whose limited function is to provide us with a partial guide for betting about the outcome of our actions within an unfathomable (micro-)environment. Such a toy-ontology can be changed along the way without qualms, if needed. At the end of the day, an ontology (be it an ontology of individuals or an ontology of some pre-individual background "field") is seen to be little more than the structure of a bundle of expectations that instructs in advance the physicist's actions. More generally, an ontology does not represent the deepest layer of our knowledge about the world, but rather the underlying body of presuppositions with which we steer ourselves to explore more efficiently the unknown.

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