ARE 'PARTICLES' IN QUANTUM MECHANICS "JUST A WAY OF TALKING"?

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Abstract

In this work we discuss the widespread use and application of the notion of *particle* within the standard understanding of quantum mechanics, trying to prove how it is not just an innocent and unproblematic "way of talking", as it is often claimed, but the expression of an atomist metaphysics that represents rather a way of perceiving and thinking that inadvertently determines our understanding of the mathematical formalism and the experimental content of quantum mechanics. We show how the retention of atomist concepts, especially due to Bohr's work, appears not only as an epistemological obstacle but furthermore as an efficient factory of false problems and misleading intuitions that have concentrated the attention of researchers for some time. Revisiting again Heisenberg's matrix mechanics, we discuss if it would be possible to advance beyond the substantialist account of QM going back to the operational-invariance of intensive quantities.

Keywords: *Quantum individuality, atomism, matrix mechanics, Bohr's atomic model.*

> *We are, to be sure, all of us aware of the situation regarding what will turn out to be the basic foundational concepts in physics: the point-mass or the particle is surely not among them.*
>
> Albert Einstein.

> *A partial truth goes on working for a time, but then, instead of complete enlightenment, a dazzling error suddenly intrudes; the world makes do with that and in this way whole centuries are duped.*
>
> J. W. Goethe

1 A History of Particles

The concept of the atom, or the more generic term 'particle', seems to be a notion so deeply rooted in contemporary physics that proposing a critique and, perhaps, a rejection of its use —at least in quantum theory— may appear at first as completely unreasonable. But we know quite well that this has not always been the case: already among the Greeks atomism was heavily questioned. Much closer in time, during the 19th century, Ernst Mach would fiercely deny the existence of atoms. However, today, when it comes to quantum physics, we all talk about "quantum particles", and in doing so we are certain we are speaking a unanimously accepted, meaningful physical discourse. But are we right in doing so? Are we saying something actually meaningful? Are these terms really adequate to the theory? And even more important: aren't atomist concepts forcing on us misleading presuppositions? Before analyzing the meaning of the particle in quantum physics, let us do a little history. First, of course, the Greeks. Atomist philosophy was born during the Vth century b.C. in the works of Leucippus and Democritus. They proposed, as many of the first philosophers, some fundamental elements out of which *physis* (nature, reality) was made of. These elements were being and not-being, which they interpreted as 'the full' and 'the void'. Being, or the full, consisted to them of indivisible bodies with a minimum size. Simple bodies. They used an adjective to describe these bodies, *átomos*, which means 'not divided', that adjective became an *ism*, and this philosophy found its name for all times: "atomism". Displaying his knowledge of the sources, Werner Heisenberg describes atomism in contrast to Parmenidean philosophy, and so he shows what, for many among the Greeks, seemed weak about the atomist proposal:

> "The antithesis of Being and Not-being in the philosophy of Parmenides is here secularized into the antithesis of the 'Full' and the 'Void'. Being is not only One, it can be repeated an infinite number of times. This is the atom, the indivisible smallest unit of matter. The atom is eternal and indestructible, but it has a finite size. Motion is made possible through the empty space between the atoms. Thus for the first time in history there was voiced the idea of the existence of smallest ultimate particles —we would say of elementary particles, as the fundamental building blocks of matter. According to this new concept of the atom, matter did not consist only of the 'Full', but also of the 'Void', of the empty space in which the atoms move. The logical objection of Parmenides against the Void, that not-being cannot exist, was simply ignored to comply with experience." [**?**, pp. 65-66]

The postulation of the void, and the identification of being with simple, independent bodies, permits us to view atomism as an example of what we usually understand as substantivalism, that is, to put it briefly, the view according to which reality is constructed by the sum of independent separated substantial bodies. But, in order to better understand Heisenberg's quote, let's stay with Parmenides for a bit. In his poem, Parmenides proposes a way which can lead us to true knowledge, if properly followed. This path is supported by a main certitude, that Parmenides puts in an amazingly brief manner: "*is* and not being is impossible" [DK 28 B]. Strangely, the conjugate verb *is* (*estín* in ancient Greek) appears without subject. *Who* or *what* is? Parmenides seems to be purposely leaving the verb without subject to differentiate his philosophy from those common already in Greek thought. If the previous or contemporary philosophers selected one or several 'elements' or substances as origin and foundation of nature (of which they primordially predicated being), or, as Heraclitus, dedicated their thought to describe the hidden order that governs reality (the *logos* of *physis*), Parmenides starts by a previous, humbler truth: any 'element' we can select, any 'order', anything of any nature, must be, first, something that *is*, must share being. And this gives new and full meaning to the notion of *being*, up to then ambiguously presupposed. A notion quite different from the elements or substances privileged by other philosophers. The simple yet universal, all-encompassing *fact of being* —as Néstor Cordero puts it [**?**]— is the origin of the Parmenidean wonder. Cordero's proposition (that we take Parmenides' being as the 'fact of being') is useful for it shows that Parmenides wishes above all not to substantialize being, not to *select* some substance as the exclusive "true" being. Parmenides' being is not a transcendent principle, is not The Being, but the all-encompassing, irreducible, fact of being —that he will later on in the poem refer to as 'what is'. But, as we have read, Parmenides thesis adds something else, it affirms the impossibility of *not-being*. In fact, it is this part of the thesis that is most extensively developed throughout the poem. According to Parmenides, when we understand being in this manner, its opposite, not-being, appears as impossible. And one of the most insisted upon ways in which Parmenides expresses this impossibility in his poem is the one that identifies not-being with *separation*: "you will not sever what is from holding to what is" [DK 28 B4]; "it is wholly continuous; for what is, is in contact with what is" [DK 28 B8.25]; "Nor is it divisible, since it is all alike" [DK 28 B8.22]. In this sense, 'not-being is impossible' means that there is no cut, no strip, no ditch, inside being, through which not-being would pass. Being has no cracks within, no interstices. There may of course be differences, it's undeniable, but there are certainly no ontological separations within what *is*. It is this impossibility that atomists, as Heisenberg claimed, simply ignore. They take being not in a Parmenidean manner as the irreducible totality of existence, but as a kind of indivisible and small body, many times repeated, as a substance unendlessly combined to construct reality, and so they postulate that not-being (for this construction to be possible) must also *be*.

Erwin Schrödinger is satisfied with a simpler description of atomism, one that does not pass through Parmenides; but his aim is to point to the fact that this ancient theory is still essentially our own: "the bodies consist of discrete particles, which themselves do not change, but recede from each other or come closer together, leaving more or less empty space between them. That was their, and that is our, atomic theory" [**?**, p. 64]. And he adds something that interests us specially as we follow the path of atomism: he explains how this ancient and quite strange theory came to be accepted in modern times and cemented in our common sense.

> "From the lives and writings of Gassendi and Descartes, who introduced atomism into modern science, we know as an actual historical fact that, in doing so, they were fully aware of taking up the theory of the ancient philosophers whose scripts they had diligently studied. Furthermore, and more importantly, all the basic features of the ancient theory have survived in the modern one up to this day, greatly enhanced and widely elaborated but unchanged, if we apply the standard of the natural philosopher, not the myopic perspective of the specialist." [**?**, pp. 82-83]

Heisenberg also describes the historical path which atomism took in modern times, specifically how it was united with the materialistic view that began to take shape in modernity. A view that, dividing reality in *res extensa* and *res cogitans*, limited physics (and natural science in general) to the study of the mechanics of this now merely material *res extensa*:

> "Matter was thought of in terms of its mass, which remained constant through all changes, and which required forces to move it. Because, from the eighteenth century onwards, chemical experiments could be classified and explained by the atomic hypothesis of ancient times, it appeared reasonable to take over the view of ancient philosophy that atoms were the real substance, the immutable building-stones of matter. Just as in the philosophy of Democritus, the differences in material qualities were considered to be merely apparent; smell or colour, temperature or viscosity, were not actual qualities of matter but resulted from the interaction of matter and our senses, and had to be explained by the arrangements and movements of atoms (...). It is thus that there arose the over-simplified world-view of nineteenth-century materialism: atoms move in space and time as the real and immutable substances, and it is their arrangement and motion that create the colourful phenomena of the world of our senses" [**?**, p. 12]

Ancient atomism was recuperated in modern times and further pushed inside the limits of a narrow materialism in which the resulting atoms were viewed as the fundamental elements of a *res extensa*, now taken as the sole object of the natural sciences.

Heisenberg also investigated how that narrow materialism of modern times came to be. He was —as his friend Wolfgang Pauli— an attentive critic of the parameters that Enlightenment established for physics in particular and natural sciences in general. He especially focused on the critical analysis of the separation that determined for physics that over-simplified object of knowledge: a world defined as a material mechanism. A narrow picture that, according to Heisenberg, enters into a crisis with the appearance of quantum mechanics. Indeed, how to account, for instance, for quantum probability, or for the intrinsic indeterminacy, in the context of this extreme form of materialism? He finds the basis of this separation was most definitely determined by Cartesian philosophy, which he introduces in contrast with Greek thought:

> "This bases of the philosophy of Descartes is radically different from that of the ancient Greek philosophers. Here the starting point is not a fundamental principle or substance, but the attempt of a fundamental knowledge." [**?**, p. 78]

René Descartes' basic aim was not, as it was for the Greeks, to decipher the meaningful complexity of nature from its inherent principles or elements, but rather "what and how can I know with certainty?" It is the adaptation to the parameters that define certainty for the subject what is fundamental here, rather than developing a way of apprehending the hidden order of nature. The question is different and the answer is different, and Descartes' answer is without question a prodigious one; one that transformed philosophy: as much as I doubt, I cannot deny that I think —since doubting is thinking—, and since I am certain that I think, I certainly am (*dubito, cogito, sum*). But Descartes finds himself locked in solipsism: he is only certain of the isolated *I*. How to advance beyond the *cogito*? How to recover reality? This is done through a version of the old ontological argument that functioned as a proof of the existence of God: God must also exist, since I have an idea of God that I could have not produced by myself (since I don't have the amount of *formal* reality to produce the amount of *objective* reality that this idea entails); and given that God exists, the world in front of me, of the *I*, cannot be entirely a deceiving illusion. But, for Heisenberg, this reconstruction is problematic, since these added relations cannot disguise the fact that he sets a fundamental division as the basis for further reasoning:

> "his starting point with the 'triangle' God-World-I simplifies in a dangerous way the basis for further reasoning. The division between matter and mind or between soul and body, (...) is now complete. God is separated both from the I and from the world. God in fact is raised so high above the world and men that He finally appears in the philosophy of Descartes only as a common point of reference that establishes the relation between the I and the world" [**?**, p. 78]

Descartes is, in principle, only certain of the isolated *I*. Then through God he establishes the existence of the world —as what the *I* has in front of him. God sets up a narrow bridge between what is fundamentally an isolated *I* and a separated, strange, world. And at the same time, by the same movement, the world is impoverished: although God functions as guarantee of the existence of the world, his work or expression is not recognizable in it. The world is at the same time guaranteed and emptied. It is the mere world, an exterior landscape that affects my senses, that appears opposed to the *I*. God is evacuated from the world and the *I*, and represents only the guarantee of their relation. But this relation between the *I* and the world is the exterior relation of two strangers, of two separated elements, and this reality now opposed to the subject and emptied of inherent meaning is defined as *res extensa*. Descartes establishes as the basis for further thinking, for the different scientific and philosophical endeavours, a fundamental separation: starting from the separation of God, the I and the world, starting from the separation between a *res extensa* and a *res cogitans*, it seems we can better determine and organize knowledge. Surely, as Heisenberg points out, it is not completely fair to exclusively accuse Descartes for this sharp separation in human knowledge, but none the less —Heisenberg adds— it is certainly he who established more definitely the basis for such a separation:

> "Of course Descartes knew the undisputable necessity of the connection, but philosophy and natural science in the following period developed on the basis of the polarity between the *res cogitans* and the *res extensa*, and natural science concentrated its interest on the *res extensa*. The influence of the Cartesian division on human thought in the following centuries can hardly be overestimated, but it is just this division which we have to criticize later from the development of physics in our time." [**?**, pp. 78-79]

Where the Greeks saw the necessity of the interconnection between "sensible" and "intelligible", between becoming and *nous* —as they knew that neither of these could be understood without the other—, modernity —at least an important part of it— was convinced by the necessity of division. And the merely 'material', alienated from what was before related to its inherent meaning, was, with time, isolated as the business of independent natural science. It is a world emptied of its essential content, its inherent meaning, its principles. An emptied world which will understandably lead to the vision of its contingency, and, in empiricist philosophy, to skepticism (which will only be avoided, in Kant's work, by projecting objectivity and order into the world of phenomena by means of the subject). This separation, with its modern redefinition of the object of physics, is something that, to Heisenberg, quantum mechanics calls into question.

But it was undoubtedly Isaac Newton who united most definitely modern materialism and atomism. He was able to translate into a closed mathematical formalism both the object of atomism together with the materialistic reduction of physical reality to *res extensa*. Newton's atomist mechanics was able not only to mathematize atoms as points in phase space, he also constructed an equation of motion which allowed to determine the evolution of such "elementary particles". The picture of the world described by Newtonian mechanics was that of small actual particles in absolute space bouncing between each other in a completely deterministic manner. An actual state of affairs evolving within an all encompassing space and time.

As Heisenberg, Schrödinger also saw this modern atomist worldview as naïve. He claimed that the term "atom" had become "a misnomer" [**?**, p. 183], and stated the fact that became evident for those involved in the development of the new quantum theory: "modern atomic theory has been plunged into a crisis. There is no doubt that the simple particle theory is too naïve." [**?**, p. 87]. What was once a basic assumption for physical thought was now exposed as an inadequate postulate, one that represented an obstacle for the new theory. Schrödinger writes: "We have taken over from previous theory the idea of a particle and all the technical language concerning it. This idea is inadequate. It constantly drives our mind to ask information which has obviously no significance" [**?**, p. 188]. But it is again Heisenberg who explains most clearly why the atomic postulate began to fail in quantum theory:

> "Let us discuss the question: what is an elementary particle? We say, for instance, simply 'a neutron' but we can give no well-defined picture and what we mean by the word. We can use several pictures and describe it once as a particle, once as a wave or as a wave packet. But we know that none of these descriptions is accurate. Certainly the neutron has no colour, no smell, no taste. In this respect it resembles the atom of

> Greek philosophy. But even the other qualities are taken from the elementary particle. At least to some extent; the concepts of geometry and kinematics, like shape or motion in space, cannot be applied to it consistently. If one wants to give an accurate description of the elementary particle —and here the emphasis is on the word "accurate"— the only thing which can be written down as description is a probability function." [**?**, p. 70]

Quantum physics goes much further than ancient atomism, which denied qualities as smell, colour or taste for their elementary particles. Now even shape or motion in space have to be excluded. What are we left with? The particle loses, in quantum theory, all of its defining characteristics. As Schrödinger writes, it even loses identity, "sameness": an "elementary particle", he says, "is not an individual; it cannot be identified, it lacks 'sameness'." [**?**, p. 183]. There's almost nothing left of it, and what's left is certainly an aspect that doesn't seem too adequate to atomism, that could perhaps be better understood outside of the atomist frame: a strange "probability" that can't be interpreted in a classical manner, by ignorance, just as a mental calculation, as an abstract probability dependent on our degree of knowledge about a real, actual particle. On the contrary, this is something that, in fact, interacts. If we want to call it a probability, it is a new kind of probability —which seems to have physical existence independently of the actualist atomist representation— of which Schrödinger rightly points out: "Something that influences the physical behaviour of something else must not in any respect be called less real than the something it influences" [**?**, p. 185].

For the founders of the theory it became evident, once the formalism of quantum mechanics had become a closed mathematical scheme, that there were too many problems to conceive the theory as describing physical reality in terms of atoms —as "tiny elementary particles living in space-time". According to Heisenberg [38, p. 3], "the change in the concept of reality manifesting itself in quantum theory is not simply a continuation of the past; it seems to be a real break in the structure of modern science". Quantum contextuality, the existence of strange superpositions, the measurement problem, the problem of quantum individuality and the problem of non-locality, among many others, showed the limits of attempting to understand quantum physics in terms of an atomist worldview. And yet we speak, still today, and unanimously, about quantum "elementary particles". This vague reference to particles has multiplied itself within contemporary physics, extending its application beyond QM to quantum field theory, string theory and —of course— the standard model of particle physics. As exposed in a recent article by Natalie Wolchover titled: "What Is a Particle?" [**?**], there is no consensus within the physics community on what is the meaning or reference of such a —supposedly— essential concept. On the very contrary, the interpretation of particles fragments itself in completely different, incompatible directions —all of which anyhow co-exist in the discourse applied by contemporary physicists. Particles are interpreted as the collapse of a quantum wave function, as the excitation of a quantum field, as the irreducible representation of a group, as vibrating strings, as the deformation of a qubit ocean, as measurement outcomes, and the list continues... In this respect, theoretical physicist at the Massachusetts Institute of Technology Xiao-Gang Wen has recognized what many students might suspect: "We say they are 'fundamental'. But that's just a [way to say] to students, 'Don't ask! I don't know the answer. It's fundamental; don't ask anymore'."

2 Revisiting Mach's Rejection of Atomism

Before Heisenberg and Schrödinger, Ernst Mach was already quite unsatisfied —to say the least— with the all-encompassing atomist view of the physical world. The rejection of atomism was an important part of his broader critique of some of the fundamental parameters of classical physics. Atoms, the main constitutive elements of the metaphysical picture of Newtonian physics, as well as absolute space and time —which acted as *a priori* forms of intuition in Kant's architectonic—, were the main focus of Mach's attack. His work would spread a critical view of the universally presupposed concepts of classical physics and, for that reason, it became a fundamental precondition for the development of both relativity theory and quantum mechanics. While Albert Einstein applied Mach's ideas in order to critically address the definition of *simultaneity* in classical mechanics, both Max Planck and Werner Heisenberg were able to advance new non-classical mathematical postulates and formalisms which could explicitly escape —thanks to Mach's work— the modern space-time representation and provide a quantitative account of a new field of phenomena. In fact, it was the critical application of Mach's observability principle to the intensive line-spectra which led Heisenberg to the construction of a closed mathematical formalism that he would call "quantum mechanics". However, even though some of Mach's ideas were becoming very popular during the first decades of the 20th Century, his criticism of atomism did not stick. Despite the insistence of Mach's anti-atomism, even the new theory of quanta ended up related to a microscopic realm constituted by elementary particles. The fact that Planck's quantum postulate precluded a continuous representation of phenomena did not seem to physicists a good enough reason to abandon the familiar image of particles moving around in a continuos spatio-temporal context. The hope was that —at some point—, sooner than later, the strange discreteness implied by the quantum of action would be redirected somehow to the classical representation. But, even if finally left aside, some aspects of Mach's critique of atomism still bare —as we will try to show— some actuality when confronted with contemporary quantum theory.

Mach's most famous arguments against atomism were, in principle, those of an empiricist loyal to the implications of his stance. As explained by Larry Laudan:

> "Mach, it is claimed, believed that the knowable world consisted solely of sensations (or, as he preferred to call them, 'elements') and their spatio-temporal contiguities and interconnections (...). Any reference to entities beyond sensation, to *Dinge an sich*, was illegitimate. All talk about external objects is just a shorthand way of speaking about our perceptions, actual or possible. Because atoms and molecules are, in principle, beyond the reach of our senses, because in short they are radically imperceptible, no theory that refers to atoms or molecules is meaningful." [**?**, p. 203]

In Mach's words:

> "If the hypotheses are so chosen that their subject can never appeal to the senses and therefore also can never be tested, as is the case with the mechanical molecular theory, the investigator has done more than science, whose aim is facts, requires of him —and this work of supererogation is an evil." [**?**, p. 57]

He took this rejection of atomism even further than the founders of the quantum theory:

> "the biological-economical interpretation of the cognitive process can perfectly well co-exist on peaceable, and indeed on friendly, terms with that of present-day physics. The only real point of difference which has so far come to light concerns the belief in the reality of atoms. (...) If belief in the reality of atoms is so important to you, I cut myself off from the physicist's mode of thinking, I do not wish to be a true physicist, I renounce all scientific respect, in short: I decline with thanks the communion of the faithful. I prefer freedom of thought." [**?**, pp. 78-79]

In continuation with the anti-realist tradition —rooted on ancient sophists as Protagoras and continued by empiricism—, for Mach the only referents of his discourse could be sensations, perceptual experiences. This entails of course that the representation of entities beyond direct observation as real independent existent elements was to be denied. Metaphysical representations, he believed, should be excluded as much as possible from scientific discourse, and atomism, as it was evident, was one of such metaphysics:

> "One and the same view underlies both my epistemological-physical writings and my present attempt to deal with the physiology of the senses — the view, namely, that all metaphysical elements are to be eliminated as superfluous and as destructive of the economy of science. [**?**]

As we will see, and contrary to his anti-atomism, this positivist stance, as it was further developed and transformed by logical positivism and its many and varied ramifications, was surely the aspect of Mach's thought that prevailed in contemporary physics and philosophy of science. But let us dig deeper in his anti-atomism because, as Laudan and others have showed, Mach's critique of atomism entails also other nuances and arguments besides the positivist refusal of metaphysics, the revision of which is undoubtedly interesting for us, since they allow to prefigure some of the critiques one can formulate about atomism in quantum mechanics up to the present. For instance, the critique of atomism's supposedly heuristic value. Despise his "sensationalist" epistemology, Mach was in fact often willing to accept a transitional and heuristic value for these "mental adjuncts", as he called them. But, as Laudan shows, Mach believed that even this weak support could no longer be proposed for the case of atomism:

> "Insofar as the atomic theory helped scientists discover connections between the appearances (as Mach concedes it did with respect to the laws of definite and multiple proportions), it was of great heuristic use. But Mach considers that atomism long ago outlived its usefulness and is now simply redundant." [**?**, p. 212]

And that "redundant" aspect was, according to Mach, not without consequences. In *Knowledge and Error* Mach points the often-misleading nature of imagination's "mental adjuncts":

> "If favourable circumstances guide the imagination in such a way that it follows or anticipate facts, we gain knowledge. However, unfavourable circumstances can direct the attention on the inessentials, promoting thought connections that do not correspond to the facts but mislead." [**?**, p. 65]

As we jump back to the present, we realize this situation doesn't seem to have changed much. Surely someone could reply today, as many in fact replied Mach, that atomism is "useful", despite its difficulties in terms of representation. Many, in fact, among physicists and philosophers, will admit that there aren't any "quantum particles", but they will add that they have, however, a heuristic value. But, even leaving aside that questionable view of theories as some sort of useful fictions, the truth is that, in quantum mechanics, atomism has not that supposed heuristic value. It is the contrary which is in fact true: as we will show, it makes us ignore essential aspect of the experimental and formal content, it makes us lose invariance, introduce an *ad hoc* collapse, assume space-time, assume separability, etc.; it is, in short, a great *heuristic obstacle*.

As we continue to revise Mach's thoughts on atomism, we find some other arguments that show some similarity with Heisenberg's and Schrödinger's. As these two, Mach also criticizes atomism place in the reductionist and overly mechanistic view of physics that he sees as originating in the 17th century. He sees modern atomism as a key constituent of an overly simplified vision of physics:

> "Modern atomistics is an attempt to make the substance concept in its naivest and rawest form [...] the basis of physics." [**?**, p. 206]

Why, then, if its heuristic value is doubtful and the worldview it creates naïve, atomism remained so present in the thought of physicists? For Mach the answer is amazingly simple: because of its "familiarity", as it is often confused with intelligibility —and one cannot help but to wonder if this is perhaps still the reason for its survival in quantum theory. As remarked by Laudan:

> "What, in Mach's view, had made the mechanistic research program so attractive was the 'misconception' that mechanical processes are more comprehensible, more intelligible, clearer than non-mechanical ones. Mach has two arguments against such Cartesian wish-fulfilment. For one thing, he maintains that most partisans of mechanistic reduction confuse intelligibility with mere familiarity" [**?**, p. 216]

3 Bohr's Atomic Model and Classical Language

There's something in Mach's positivism, something of fundamental importance, the lack of which in most of the positivist stances since, undermines them; something that should be again pointed out: it is Mach's rigorous insistence. The quality of his positivism is in fact based on it. Mach's positivism is inseparable from a continuous critical attitude, from the need to be constantly attentive in order to cast aside unjustified although familiar terms and presuppositions that naturally and inadvertently determine once and again our thoughts. Positivism, if it is to have a fruitful impact on scientific endeavors, is not gained through the declaration of a stance, but constantly through a continuous effort. Mach's tenacious insistence in explicitly excluding the legitimacy of atomism shows that a rigorous positivism is not one that, in an instant, by mere decision, magically becomes free of "metaphysics", of theoretical presuppositions inherent to thinking and observing. On the contrary, the methodological and critical value that positivism can have, the skeptical necessity it can express, requires a constant and conscious attention regarding the presupposed parameters and its effects. Its "objectivity" has to be gained regularly. It points with insistence to the necessary work of skepticism to free as much as possible the scientific endeavor of inadequate presuppositions that block its path. A "direct" access to what is perceived is never magically gained by mere will. On the contrary, the constancy of the critical revision is the only thing that approaches it somehow to its goal. Let us compare for an instant Mach's attitude to that of his contemporary heirs, who, while affirming their loyalty to *what is observed*, so easily and continuously talk of elementary particles which they are not capable of defining, not even experimentally. And this also takes us to the realisation that the two physicists who applied Mach's positivism seriously to the development of the two main theories of the 20th Century were in fact essentially "realists", namely, Einstein and Heisenberg.[1] While Einstein applied Mach's criticism to classical mechanics in order to escape absolute space-time and revisit the notion of *simultaneity*, Heisenberg applied Mach's observability principle in order to leave behind classical

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[1] It is true that Heisenberg followed on many occasions Bohr's line of research, however, it is also quite clear that during his elder years he would become closer to a realist understanding of physics.

presuppositions —imposed by Bohr's model of the atom and his "magical" correspondence principle (see [**?**])— and focus instead on the intensive spectra that were actually observed in the lab. In this respect, the contrast between the attitude of Einstein and Heisenberg and that of the Danish physicist could not be more extreme. What for Bohr had to remain free of critic, had to maintain its universal applicability, even in the case of quantum mechanics, was classical terminology, classical concepts. Why? Because, he claimed —renouncing to engage in the critical efforts of some of his contemporaries— it is the language of "common" perception, and thus of all physical experience:

> "all accounts of physical experiences are, of course, ultimately based on common language, adapted to our surroundings and to tracing relationships between cause and effect" [**?**, p. 1]
>
> "the description of the experimental arrangement and the recording of observations must be given in plain language" [**?**, p. 3]

Bohr's proposal was at the same time positivistic and anti-Machian. On the one hand he redirected the problem of the representation of the quantum phenomena to that of the description of (classical) experimental arrangements. In this manner, and "positivistically", he redirected the attention from the representation of the new aspects of the quantum realm to the description of individual experiences. But, at the same time, he denied the need for a critical revision of the language of that description, of the metaphysical presuppositions it carried. He argued that, since the measuring instruments of the experimental arrangement were "big" and "heavy", everything could be described in "plain" (classical) language: "the use, as measuring instruments, of rigid bodies sufficiently heavy [...] allow a completely classical account of their relative positions and velocities" [**?**, p. 3]. This represents an anti-Machian attitude in its uncritical acceptance of the concepts of classical physics, which support, of course, a classical metaphysics. It is a positivistic stance (since it refuses the possibility of representing a real quantum "state of affairs" and concentrates solely on the description of measurements), but without its skeptical and critical weapons. A way to allow an empiristic and positivistic stance without the difficult task of engaging in the critique of classical metaphysics.

But, of course, not even concentrating on the description of "heavy" measuring instruments what is expressed in quantum physics could be signified completely through classical concepts. However, since that familiarity of the classical terms was, according to Bohr, irreplaceable, instead of paving the way to new conceptual hypothesis, he proposed that we "generalize" the classical language. By *generalizing* he meant that we should now simply accept, in using that language, the presence of inconsistencies and paradoxes, refusing at the same time to give it its representative power, its capacity to represent consistently —through (formal) *invariance* and (conceptual) *objectivity*— a subject independent state of affairs. He loosened the classical language in ways which contradicted its own presuppositions and expelled its consistency. And, by emptying this conceptual system of its representative capacity he reframed it as a mere form of communication: "all departures from common language and ordinary logic are entirely avoided by reserving the word 'phenomenon' solely for reference to unambiguously communicable information" [**?**, p. 6]. Faced with the inadequacy of classical concepts in relation to quantum physics he tried a different path than those that were starting to appear in the works of others like Heisenberg, Pauli or Schrödinger: not to abandon those classical concepts, but to "generalize" them. The problem, for Bohr, was not that of developing an adequate representation of the quantum theory according to its radically non-classical formalism and experimental content; the problem for him was: *what do we need to do in order to keep using classical concepts.* As he explained:

> "The problem with which physicists were confronted [after Planck's discovery] was therefore to develop a rational generalization of classical physics, which would permit the harmonious incorporation of the quantum of action" [**?**, p. 2]

It is then in this positivistic yet anti-Machian manner that modern atomism was preserved and, at the same time, supposedly emptied of its representational meaning.

It is —let's add— a bit shocking to realise, when revising Bohr's texts, that he never truly provided a justification for the supposed impossibility to replace the conceptual system of classical physics. He said it was "evident", "obvious", that it was the only language of our "common" perception, but he provided no true evidence, no development capable of explaining how he understood the supposedly unavoidable relation between perception and such classical concepts. And part of the shock comes from the fact that, when only briefly revising the history of physics, we find that in fact it is the contrary that is true, that different conceptual systems often arise. Both Heisenberg and Einstein pointed in many occasions to this fact:

> "The history of physics is not only a sequence of experimental discoveries and observations, followed by their mathematical description; it is also a history of concepts. For an understanding of the phenomena the first condition is the introduction of adequate concepts. Only with the help of correct concepts can we really know what has been observed." [**?**, p. 264]

> "Concepts that have proven useful in ordering things easily achieve such an authority over us that we forget their earthly origins and accept them as unalterable givens. Thus they come to be stamped as 'necessities of thought,' 'a priori givens,' etc. The path of scientific advance is often made impossible for a long time through such errors." [**?**]

On the contrary, Bohr's "generalization" of the classical language within quantum physics would retain the atomist discourse (see [**?**]) —exported later on to quantum field theory, string theory and the standard model— but devoided of its sistematicity. A clear example of this is his famous model of the atom. In 1913 Bohr introduced Planck's quantum postulate as a fundamental element of his model of the Hydrogen atom generating an abstract set of rules capable of predicting a series of spectral lines. These operational rules, framed in accordance with the modern atomist discourse of classical physics, created a very simple image comforting to most physicists: electrons moved in orbits around the nucleus just like planets orbited the sun. Accordingly, the microscopic realm was nothing but a reflection of our own planetary system. However, the high price to pay for introducing this narrative was that the model became essentially inconsistent and incoherent. The inconsistencies were both formal and conceptual. From a conceptual perspective, it is clear that the existence of *discrete* quantum orbits within a *continuous* space simply did not add up. How could space be defined in discrete terms? Why did electrons follow continuous trajectories within confined orbits but where unable to reach the outer regions of space? How could they actually disappear from one position in space and re-appear in another one without describing a trajectory? Where were electrons supposed to go within this apparently magical process? Given they were in circular motion, why did charged electrons not irradiate energy and collapse to the nucleus? None of these questions had a convincing answer in Bohr's model. From a formal perspective the inconsistency was even more explicit. Planck's discrete representation of energy implied, through the formula $E = \frac{m}{2}v^2$ (where $v = \frac{dx}{dt}$), that space and time had to be also considered as discrete right from the start: if *energy* was —according to Planck— fundamentally *discrete* (ΔE) then *velocity* had to be discrete as well, and consequently, also *space* and *time* ($v = \frac{\Delta x}{\Delta t}$). Discreteness was everywhere. Of course, the idea of keeping classical space and time and rendering them discrete doesn't seem possible. We might recall that the essential step for the development of classical mechanics was the creation of infinitesimal calculus —by Newton and Leibniz— which allowed a rigorous mathematical definition of the *continuum* and, consequently, a consistent mathematical representation of both space and time. In contraposition to classical physics, Planck's quantum of action marks not only the birth of a new theory but —more importantly— the radical departure from the consideration of the continuous space-time representation of modern science as the *topos* of physics. A departure that would not be accepted so easily and —let us remark— continues to burden even today not only the countless interpretations but also the attempts to unify QM with general relativity. Against the radicalness of Planck's finding, Bohr was applying classical images and pictures to his model gaining the sympathy of many physicists who were not ready to give up on their "commonsensical" space-time atomist way of thinking. But very cleverly Bohr argued at the same time that, anyhow, all this reference to small particles was "just a way of talking", not a true description of what was going on in an essentially irrepresentable quantum realm. Thus, the fact that no single particle was ever actually described within his model did not stop him from talking about them. Furthermore, Bohr was introducing with his atomic model a very astute misdirection: according to Bohr, the electrons orbiting the nucleus were capable of performing spectacular "quantum jumps", suddenly disappearing in one orbit and immediately re-appearing in another. Physicists were immediately captured by this fantastic new phenomenon. As a consequence, the focus of attention was drawn away from the critical consideration of the inadequacy of atoms to the existence of quantum jumps and the trajectory of electrons. Bohr had successfully steered the discussion away from the legitimacy of the atom itself and into the interpretation of one of its supposed properties —quietly accomplishing the acceptance of atoms. The fact that these "jumps" had no experimental support nor connection whatsoever to the mathematical formalism did not seem to matter all that much. After all, as Bohr stressed continuously, the quantum realm was "extremely weird" and "un-intuitive". The only exception to the acceptance of Bohr's scheme of understanding came from Einstein and Schrödinger. As recalled by Heisenberg [23, p. 73], Schrödinger consistently argued, during a discussion with Bohr that took place in Copenhagen in 1926, against the existence of the discrete leaps introduced by the Danish physicist concluding that "the whole idea of quantum jumps is sheer fantasy." However, and very astutely, Bohr would turn things completely upside-down in his response to Schrödinger:

> "What you say is absolutely correct. But it does not prove that there are no quantum jumps. It only proves that we cannot imagine them, that the representational concepts with which we describe events in daily life and experiments in classical physics are inadequate when it comes to describing quantum jumps. Nor should we be surprised to find it so, seeing that the processes involved are not the objects of direct experience." [23, p. 74]

A brief analysis of that answer allow us to point out an ambiguous aspect of Bohr's proposal that was however —and still is— very influential on the interpretation of quantum physics: Bohr was maintaining the existence of those quantum jumps and at the same time rendering all critical tackling of them —and all other attempts to represent the phenomena in question— impossible, by characterizing them as beyond our imagination, beyond our ability to represent them. There are atoms with electrons that take "quantum" jumps, and at the same time they are beyond our imagination. He crystallized an atomistic metaphysics as the common sense understanding of the quantum realm, and at the same time he rendered the critique of that representation simply impossible.[2] In this way, the application of the atomist representation mixed together with the impossibility to represent the quantum realm would become one of the most effective shields against any rational criticism.

4 The Observation of Intensive Spectra: Heisenberg and Invariance

After Bohr's proposal, physicists were stuck with the problem of determining the trajectories of electrons inside the atom. Quantum jumps had acted as a magnet that concentrated the attention of all physicists. The unjustified claims made by Bohr within his model, presented in terms of general principles and rules, had caught the attention of everyone. Even Heisenberg had been captured by Bohr's research program, which focused in the description of the elusive trajectories of irrepresentable quantum particles and their relation to classical physics. Fortunately, by 1924, Wolfgang Pauli —following the critics of Arnold Sommerfeld— had convinced Heisenberg that the Bohrian narrative was complete nonsense. Instead of trying to describe trajectories of unseen corpuscles, Heisenberg would reframe the problem —following Mach's positivistic ideas— exclusively in terms of observable quantities. As explained by Jaan Hilgevoord and Joos Uffink [**?**]: "His leading idea was that only those quantities that are in principle observable should play a role in the theory, and that all attempts to form a picture of what goes on inside the atom should be avoided. In atomic physics the observational data were obtained from spectroscopy and associated with atomic transitions. Thus, Heisenberg was led to consider the 'transition quantities' as the basic ingredients of the theory." That same year, he would present his groundbreaking results in the following manner: "In this paper an attempt will be made to obtain bases for a quantum-theoretical mechanics based exclusively on relations between quantities observable in principle." Emancipating himself completely from classical ideas, Heisenberg was able to create a completely new mathematical formalism which escaped many of the essential features present in infinitesimal calculus —required for the consistent account of classical mechanics. As he would recall many years later in his autobiography:

> "In the summer term of 1925, when I resumed my research work at the University of Göttingen —since July 1924 I had been *Privatdozent* at that university— I made a first attempt to guess what formulae would enable one to express the line intensities of the hydrogen spectrum, using more or less the same methods that had proved so fruitful in my work with Kramers in Copenhagen. This attempt lead me to a dead end —I found myself in an impenetrable morass of complicated mathematical equations, with no way out. But the work helped to convince me of one thing: that one ought to ignore the problem of electron orbits inside the atom, and treat the frequencies and amplitudes associated with the line intensities as perfectly good substitutes. In any case, these magnitudes could be observed directly, and as my friend Otto had pointed out when expounding on Einstein's theory during our bicycle tour round Lake Walchensee, physicists must consider none but observable magnitudes when trying to solve the atomic puzzle." [**?**, p. 60]

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[2] It is interesting also to point out that, for Bohr, the discreteness of the quantum of action implied "evidently" that we had here affair with individuals of an atomistic nature. What is curious, and above all revealing, about this, is that the same aspects of quantum mechanics that for Bohr "evidently" entailed an atomistic representation, were those that for Schrödinger, for instance, made the atomistic terms "misnomers" and required the recognition of the lack of classical individuality that was revealed in quantum physics. Contrary to Schrödinger, for Bohr "there can be no question of giving up the idea of individuality of the elementary particle; for this individuality forms the secure foundation on which the whole of the recent development of the atomic theory depends" [**?**, pp. 10-11]

Clearly, there are some essential points that need to be recognized in Heisenberg's development of matrix QM:

- The abandonment of Bohr's atomist narrative and research program which focused in the description of unobservable trajectories of irrepresentable quantum particles.
- The consideration of Mach's observability principle as a methodological standpoint for the development of a unified, consistent, coherent and invariant mathematical formalism.
- Consequently, the replacement of Bohr's fictional trajectories of irrepresentable electrons by the consideration of the *intensive quantities* appearing in line spectra that were actually observed in the lab.

Once Heisenberg's matrix QM had been developed, the question of representation, still grounded on the spatiotemporal substantialist understanding of physical reality, would become an essential weapon used against a formalism which, departing from differential calculus, would be regarded by physicists as "too abstract", "too unintuitive". Just six months later, in January 1926, the sudden appearance of Schrödinger's wave equation, which reintroduced the mathematics of infinitesimal calculus and promised the restoration of a continuous space-time representation, would bury the possibilities of a conceptual development of matrix QM. The many promises of wave mechanics would never be realized and Schrödinger's formulation would be very soon re-appropriated by Bohr's approach where new "quantum jumps" and fictional —inconsistent— narratives would be established as dogma in order to support an algorithmic —also inconsistent— "recipe" to account for measurement outcomes interpreted as "quantum particles" (see [**?**]). The triumph of Bohr's approach to QM would be finally accomplished through the binary observational atomist re-formulation presented by Paul Dirac in 1930, reinforced two years later by the work of John von Neumann. As we shall discuss in the following section, this triumph implied a strategic silent alliance with logical positivists as the natural expression within science of a new anti-realist *Zeitgeist* that would rule –almost without opposition— through the whole 20th Century.

5 Bohr's Triumph and Dirac's Observational Atomism

What Bohr had accomplished through his atomic model would be extended and reproduced later on —not only by himself— in order to generate an "interpretation" of QM where the reintroduction of classical concepts —although "generalized"— would allow to restrict the problems of the theory to the justification of a —presupposed— classical "common sense" exposed by the evidence of 'clicks' in detectors as well as macroscopic measuring apparatuses. Through the principles of correspondence and complementarity Bohr would be able to justify the complete lack of theoretical and experimental support and —at the same time— fill this void with a pendular rhetoric in constant motion between the (anti-realist) reference to subjective observations and measurements processes, the (supposedly realist) reference to macroscopic objects, and —even more importantly— an irrepresentable quantum realm constituted by elementary particles (see [**?**]). Through the *correspondence principle* the Danish physicist would maintain a discourse about microscopic particles as the constituents of the most fundamental layer of reality, arguing at the same time that, after a certain "limit", given certain quantities, we could neglect the strange quantum aspects of the description and start talking in a classical manner about macroscopic objects. Bohr thus transferred the problem of understanding the quantum formalism and phenomena to the new problem of understanding QM as a generalization of classical physics. This principle expressed "the asymptotic approach of the description of the classical physical theories in the limit where the action involved is sufficiently large to permit the neglect of the individual quantum" [**?**, p. 86]. In short, "the aim of [the correspondence principle] was to let a statistical account of the individual quantum processes appear as a rational generalization of the deterministic description of classical physics" [**?**, p. 87]. With the *principle of complementarity*, on the other hand, Bohr would be able to reintroduce the lost classical reference to waves and particles regardless of the complete lack of consistency: "We must, in general, be prepared to accept the fact that a complete elucidation of one and the same object may require diverse points of view which defy a unique [consistent] description." This radically conservative principle would allow him to justify not only the inconsistent use of contradictory representations (referring to the same state of affairs) but also the prohibition to develop new concepts. Bohr [**?**, p. 7] stated that: "[...] the unambiguous interpretation of any measurement must be essentially framed in terms of classical physical theories, and we may say that in this sense the language of Newton and Maxwell will remain the language of physicists for all time." In this respect, he argued "it would be a misconception to believe that the difficulties of the atomic theory may be evaded by eventually replacing the concepts of classical physics by new conceptual forms." Giving up on the fundamental principle of invariance —essential within physics to discuss about the same state of affairs from different perspectives— he claimed that since no contradiction would be found within a single experiment, QM could be regarded as a theory as objective as classical mechanics. Of course, unlike in classical physics, the contradiction would arise immediately when anyone, searching for the necessary invariance, would attempt to consider these multiple representations as making reference to one and the same state of affairs (see [**?**]). As explained by Jean-Yves Béziau [**?**]: "[Bohr] argues that there are no direct contradictions: from a certain point of view 'K is a particle', from another point of view 'K is a wave', but these two contradictory properties appear in different circumstances, different experiments. Someone may ask: what is the absolute reality of K, is K a particle or is K a wave? One maybe has to give away the notion of objective reality." Now we could speak of particles, and we could speak of waves, but we had to renounce objectivity, namely, the possibility of the *reference* of multiple phenomena to a common (conceptual) *moment of unity*. Although the price to keep the classical terms in use for quantum physics seemed a bit high, the new generation of physicists trained in an instrumentalist fashion would be willing to pay. Once again, Bohr was able to maintain the legitimacy of classical concepts for quantum physics, to prevent new theoretical developments by rendering objectivity directly impossible, and to redirect physicists to new spectacular "quantum images" he had himself created.

Concomitant to Bohr's work in QM, during the first decades of the 20th Century, positivism continued to gain momentum, attempting to fight metaphysical thought through the development of Mach's ideas and his empiricist standpoint. Its main attack to metaphysics was based on the idea that one should focus in "statements as they are made by empirical science; their meaning can be determined by logical analysis or, more precisely, through reduction to the simplest statements about the empirically given" [**?**]. Logical positivists cemented an understanding of scientific theories, influential even today, grounded on observations (believed to be free of metaphysical presuppositions) and a formal mathematical structure capable of predicting them. For the first time, all metaphysical endeavors, and conceptual developments in general, were evacuated from the fundamental structure of scientific theories and reduced to mere and unnecessary storytellings. According to this scheme, physical concepts are not essentially needed, since the analysis of a theory can be done by addressing only the logical structure of theories themselves. The role of concepts becomes then accessory: "adding" a metaphysical narrative might help us to "picture" what is going on according to an already empirically adequate theory. But it would be a mistake to take this 'interpretation" too seriously. Logical positivism and post-positivism established in an explicit manner something that in Bohr's epistemic claims was still ambiguous, and evacuated metaphysics from its fundamental role in scientific theories, turning it into just a mere *narrative* one can —most inconsequentially— add to calm metaphysical anxieties about the unobservable. It is in this context that the triumph of Bohr was cemented by his unspoken alliance with logical positivism. An alliance sealed in 1930 in the book *The Principles of Quantum Mechanics* in which Dirac's axiomatic re-formulation would combine with great mastery both positivist ideas regarding theories with Bohr's interpretation of QM. Two years later, in 1932, John von Neumann's [**?**] *Mathematische Grundlagen der Quantenmechanik* would continue to pave the Bohrian road extended by Dirac's axiomatic formulation. Dirac and von Neumann would cement Bohr's interpretation, together with a positivistic view of science, as the "standard" approach to QM —also known as the "Dirac-von Neumann formulation" or the "Copenhagen interpretation" of quantum theory.

Dirac's book is perhaps one of the most clear and influential examples of how inadequate atomistic concepts produced misdirections, how they are not only epistemological obstructions but also a source of false problems and misleading debates, in which we find ourselves still today trapped. From the beginning Dirac speaks of particles, taking atomism for granted, while at the same time insisting endlessly on his positivistic commitment to take only actual observations as meaningful. Assuming such a positivist standpoint, Dirac stresses explicitly a warning to the attentive reader: "[it is] important to remember that science is concerned only with observable things", and also, that "the main object of physical science is not the provision of pictures, but the formulation of laws governing phenomena and the application of these laws to the discovery of phenomena. If a picture exists, so much the better; but whether a picture exists or not is a matter of only secondary importance" [**?**, p. 10]. Dirac claims that his aim is to build a rigorous axiomatic formulation of QM from scratch. However, it is interesting that the opening paragraph of his book is dedicated to affirm that this doesn't mean we have to abandon the "best" things about the classical theory. We suspect, right from the start, that we are in a Bohrian world. The need to preserve the classical language while at the same time "generalizing" it appears in the beginning of Dirac's book in a somewhat indefinite, ambiguous manner: although the new theory implies profound changes, we are able to maintain what is "attractive" about the classical theory in the new scheme (which is, he argues, even "more elegant and satisfying"):

> "Classical mechanics has been developed continuously from the time of Newton and applied to an ever-widening range of dynamical systems, including the electromagnetic field in interaction with matter. The

> underlying ideas and the laws governing their application form a simple and elegant scheme, which one would be inclined to think could not be seriously modified without having all its attractive features spoilt. Nevertheless it has been found possible to set up a new scheme, called quantum mechanics, which is more suitable for the description of phenomena on the atomic scale and which is in some respects more elegant and satisfying than the classical scheme. This possibility is due to the changes which the new scheme involves being of a very profound character and not clashing with the features of the classical theory that make it so attractive, as a result of which all these features can be incorporated in the new scheme." [**?**, p. 1]

But what is it that Dirac considers "attractive" in classical mechanics? What is he able to save from the classical theory and what does he abandon in this new scheme called *quantum mechanics*? Already in the following paragraphs we learn of one of the things that is lost, what he calls "determinacy": the possibility of exactly relating the formalism with the results of experiments. In a directly Bohrian way, and prepared by one of his numerous reminders of the positivistic stance he takes, Dirac presents the major transformation the new scheme brings as essentially a *limit:* when investigating the things QM talks about, the disturbance entailed by observation is no longer negligible (this, according to Dirac, is exactly what characterizes those things as "small"), and so —since for him knowing is observing— a limit is established to our possible knowledge through the irreducible inadequacy between theory and experimental results. This "unavoidable disturbance" —which in the case of Bohr was explicitly related to the quantum of action— is what requires of us to produce a new scheme. Quantum mechanics is defined by Dirac as the theory developed to deal with the things which can't be observed without a non-negligible disturbance:

> "At this stage it becomes important to remember that science is concerned only with observable things and that we can observe an object only by letting it interact with some outside influence. An act of observation is thus necessarily accompanied by some disturbance of the object observed. We may define an object to be big when the disturbance accompanying our observation of it may be neglected, and small when the disturbance cannot be neglected. This definition is in close agreement with the common meanings of big and small. It is usually assumed that, by being careful, we may cut down the disturbance accompanying our observation to any desired extent. The concepts of big and small are then purely relative and refer to the gentleness of our means of observation as well as to the object being described. In order to give an absolute meaning to size, such as is required for any theory of the ultimate structure of matter, we have to assume that there is a limit to the fineness of our powers of observation and the smallness of the accompanying disturbance —a limit which is inherent in the nature of things and can never be surpassed by improved technique or increased skill on the part of the observer. If the object under observation is such that the unavoidable limiting disturbance is negligible, then the object is big in the absolute sense and we may apply classical mechanics to it. If, on the other hand, the limiting disturbance is not negligible, then the object is small in the absolute sense and we require a new theory for dealing with it [i. e., quantum mechanics]." [**?**, pp. 3-4]

It seems that according to Dirac the things quantum mechanics talks about are thus essentially similar to those that correspond to classical mechanics, and that the difference is related only to their size. This difference in size entails however, according to him, an important change: we are referring to things that are "too small" to observe them without producing a disturbance which is no longer negligible —introducing in a Bohrian fashion the subject, from which "big" and "small" are actually considered, as conditioning the theory. This is what for Dirac calls for a new theory, this is what produces all departures from classical physics. But this story of the "disturbance" is really quite strange when one takes a step back to analyze it. In classical physics "disturbance" and "size" play no role whatsoever in the representation provided by classical mechanics, electromagnetism or classical statistical mechanics. Nor the subject nor the measurement process play any role in these theories. As it is well known, theories do not come with a "user's manual" that tells physicists how to measure the state of affairs represented through concepts and mathematical equations. Theories describe —in different ways— actual states of affairs which evolve according to deterministic equations and given some initial conditions it is possible to compute the final state of affairs. Now, in the original version of quantum mechanics developed by Heisenberg we also have a deterministic equation which provides, given the initial conditions, the final state of affairs. In this respect, if we stick to the intensive representation provided by Heisenberg's QM, the situation is actually exactly the same as in classical mechanics. There is no "disturbance" nor "size" to be considered. Of course, this situation changes drastically if we impose a reference —which is not part of the mathematical formalism— to single measurement outcomes. So why would the original reference to intensities in QM be such a major problem? In fact it is not (see for discussion [**?**]). It has only become one because: 1) We assumed atomism, particles, right from the start, and of course particles cannot be described in intensive terms; from an atomist perspective we impose a representation in terms of binary properties. Because of a dogmatic presupposition —namely, the reference to atoms— we were from the very beginning unable to accept in its terms what the theory and the phenomena were pointing to; and thus we assumed something was missing. And 2) By the combination of a presupposed atomist metaphysics with a positivist stance, not only did we take the observations for the object of the theory but, furthermore, we identified single measurement outcomes directly with particles (we say, for instance, we "observe a particle when a 'click' happens in a detector"). And so, we put all our attention not only in actual observations but uniquely in the single measurement outcome, already understood as a particle. We were only capable of taking the single outcome, and never a multiplicity, as significant. We assumed that science is concerned only with actual observations, and since we presupposed atomism right from the start, since we think atomistically, we directly took the observations for particles. And of course, in almost all experiments, a theory that talks about intensive quantities has little to say about an isolated, independent single outcome. From a perspective where quantum mechanics makes reference to intensive values a single outcome means almost nothing. A single event is obviously unable to account for the intensive pattern QM refers to. A 'pattern' or 'distribution' requires the repetition of many different 'clicks'. Instead, Dirac claims that the equations of quantum physics are connected only indirectly to experimental results, but this is only so because he puts his focus on single measurement outcomes —disregarding the original reference of QM to intensities. Everything which is not a prediction of a binary outcome is considered by Dirac as an *uncertain* prediction. He is pushed to that conception by the influence of atomism over his interpretation of the formalism, of experiments and observation itself. But if we don't assume atomism right from the start, we might be open to consider that the physical elements of the theory are originally of an intensive —and not a binary— nature. And if we don't assume that atomistic positivism which only sees the single outcome as significant, we will be able to perfectly expose those elements through observation without any "disturbance" getting in our way.

But let us take things a bit slower and see exactly how this identification of the particle with the single outcome comes to be in the first chapter of Dirac's book, and how it gives birth to the famous "collapse" of quantum superpositions. Attempting to arrive at a formulation of the *Principle of Superposition of States* (which is the aim of the first chapter), Dirac considers the case provided by the polarization of light. From the start, however, he frames this case in atomistic terms. To him, a beam of plane-polarized light has to be considered as composed of particles: "One must consider, for instance, a beam of light plane-polarized in a certain direction as consisting of photons each of which is plane-polarized in that direction and a beam of circularly polarized light as consisting of photons each circularly polarized. Every photon is in a certain state of polarization, as we shall say" [**?**, pp. 4-5]. The concern for Dirac is "how to fit in these ideas with the known facts about the resolution of light into polarized components and the recombination of these components" [**?**, p. 5]. Before advancing let us only say that a rigorous positivist would be inclined to start from those facts about the resolution of light and not from the atomist presupposition that we should "fit in" taking trajectories for granted. But, in any case, Dirac directs us to a specific example:

> "Suppose we have a beam of light passing through a crystal of tourmaline, which has the property of letting through only light plane-polarized perpendicular to its optic axis. Classical electrodynamics tells us what will happen for any given polarization of the incident beam. If this beam is polarized perpendicular to the optic axis, it will all go through the crystal; if parallel to the axis, none of it will go through; while if polarized at an angle a to the axis, a fraction $sin^2(\alpha)$ will go through." [**?**, p. 5]

In accordance with his initial concern, the question Dirac asks us to consider in respect to this example, the question that will guide his analysis is: "How are we to understand these results on a photon basis?". It is evident that this question does not arises "positivistically" from the observations, that only because he assumed atomism it has become the main question, and it is this question —and not the results of experiments— what will give rise to the essential need to introduce a new "quantum jump" (i.e., a collapse) in order to bridge the gap between superpositions and measurement outcomes. In any case, when trying to answer that question, the first two cases (perpendicular and parallel polarization in regards the optic axis) pose no problem: "We merely have to suppose that each photon polarized perpendicular to the axis passes unhindered and unchanged through the crystal, while each photon polarized parallel to the axis is stopped and absorbed" [**?**, p. 5]. The difficulty arises only with the third case: "Each of the incident photons is then obliquely polarized and it is not clear what will happen to such a photon when it reaches the tourmaline" [**?**, p. 5]. When imagining the beam as composed of a number of particles, the difficulty to understand the results of the experiment is given as:

what happens to *each* of the photons? What happens in this context to a *single* photon? Will it pass or will it be absorbed? How to reconcile the fact that only a fraction of the beam goes through with the notion that it is made of individual particles? How to understand the meaning of that fraction in relation to each of the particles? According to Dirac, to answer this question we must imagine a new experiment, specifically aimed at this difficulty, since "Only questions about the results of experiments have a real significance and it is only such questions that theoretical physics has to consider" [**?**, p. 5]. He presents then an imaginary example where a beam of obliquely polarized light is composed of only a single photon:

> "In our present example the obvious experiment is to use an incident beam consisting of only a single photon and to observe what appears on the back side of the crystal. According to quantum mechanics the result of this experiment will be that sometimes one will find a whole photon, of energy equal to the energy of the incident photon, on the back side and other times one will find nothing." [**?**, pp. 5-6]

Dirac has finally *identified the single particle with the single outcome* (what we find in the back of the crystal is "the whole photon", or nothing at all) and thus he has enthroned the single measurement outcome as what is most significant. We can clearly trace the path, the reductionistic path, leading from the atomist presupposition to this identification: the assumption of atomism applied to a case regarding polarized light led us to focus on the problem of what happens to *each* particle. This, in turn, made us imagine the example of a beam composed of only a *single particle*, and finally, prepared by a positivistic declaration, to interpret directly the *single outcome* as that single particle. A shift from the atomistic understanding of physical phenomena to the identification of the actual observation with a particle. The presupposed atomism was combined with the positivist notion that only actual experimental outcomes have real significance, as a result the actual individual observation was taken directly as a particle —and for that reason only the single outcome became what is mainly significant, what the theory must above all explain, *save.* Dirac does not actually take results of experiments as what has significance, but only results already colored by the glasses of atomism, already adapted to atomism. In this way, let us add, he rendered dogmatic the empiricism that corresponds to positivism, he made a dogmatic atomistic attitude pass for positivism. The atomistic presupposition resulted in a unilateral focus on the single outcome. What is actually less meaningful in the context of quantum mechanics became what is most important. The unilateral focus on the single outcome has prevented us from rigorously taking into consideration the observations from experiments related to QM.

Dirac continues: "If one repeats the experiment a large number of times, one will find the photon on the back side in a fraction $sin^2(\alpha)$ of the total number of times. Thus we may say that the photon has a probability $sin^2(\alpha)$ of passing through the tourmaline and appearing on the back side (...) and a probability $cos^2(\alpha)$ of being absorbed" [**?**, p. 6]. Since he has presupposed that we are talking about particles, and since he identified the particle and the single outcome ("one will find the photon..."), the multiplicity of outcomes can only refer for Dirac to the repetition of the particle. The consequence Dirac takes from this is that the statistics arising from the multiplicity of outcomes can only be the measure of a probability of occurrence of a given outcome, understood already as a particle. The probabilistic interpretation of quantum mechanics has its origins in the atomistic presupposed worldview, as it is projected in the understanding of the formalism and the experimental results. Because of his atomist presuppositions, as they informed his positivistic stance, Dirac enthroned the single outcome, and for that reason he was not capable of taking the multiplicity as something more than the measure of something secondary, not fully real, dependent on what must be real (the 'particle' as the observed 'click' in the detector), and this is why he ended up disregarding what are in fact the main invariant quantities of the theory, those that are always predicted with certainty (i.e., intensities) independently of the context of inquiry, as mere probabilities of something else.

In the following paragraph, Dirac confesses perhaps —knowingly or not— his main motivation. When referring to the probabilistic interpretation just sketched, he expresses the reason behind it: "In this way we preserve the individuality of the photon in all cases" [**?**, p. 6]. It was the need to preserve the individuality of the particle (something that, as we said earlier, Schrödinger claims that is evidently lost in quantum mechanics) what, at least for a great part, motivates Dirac's interpretation, and not only "what is observed". Maybe now we can answer, at least in part, the question posed earlier about which of the aspects of classical mechanics were for Dirac "attractive" and had to be saved in the new scheme, and which had to be abandoned. The atomist metaphysics and its language are saved, and, on the contrary, invariance and —as we said earlier— "determinacy" are lost: "we are able to do this, only because we abandon the determinacy of the classical theory." [**?**, p. 6].

But Dirac is not yet satisfied. Many questions remain still unanswered, "questions about what decides whether the photon is to go through or not and how it changes its direction of polarization when it does go through" [**?**, p. 6]. Although those questions cannot, according to Dirac, be investigated directly by experiments, and what has already been said regarding the probability of the different outcomes "answers all that can legitimately be asked about what happens to an obliquely polarized photon when it reaches the tourmaline" [**?**, p. 6], he finds in his positivist stance a reason to advance a little further in his explanation in order to produce a "general scheme", a secondary representation supposedly capable of relating the different cases:

> "Nevertheless some further description is necessary in order to correlate the results of this experiment with the results of other experiments that might be performed with photons and to fit them all into a general scheme. Such further description should be regarded, not as an attempt to answer questions outside the domain of science, but as an aid to the formulation of rules for expressing concisely the results of large numbers of experiments." [**?**, p. 6]

With this "further description" his "principle of the superposition of states" is for the first time formulated:

> "It is supposed that a photon polarized obliquely to the optic axis may be regarded as being partly in the state of polarization parallel to the axis and partly in the state of polarization perpendicular to the axis. The state of oblique polarization may be considered as the result of some kind of superposition process applied to the two states of parallel and perpendicular polarization." [**?**, p. 6].

By following Dirac's argument, as we have been doing, we are able to see how his principle of superposition is connected to his probabilistic ignorance interpretation about a single measurement outcome (that, as we said, results from Dirac's atomism as it informs his positivistic view). In terms of experimental results, Dirac —following Born's interpretation of the quantum wave function— interpreted that quantum mechanics talks about the probabilities of certain occurrences, of certain spatiotemporal events. But from there he wants to arrive at a description of the particle. What he does then is to directly project those results of experiments into the particle itself, he transforms what are supposedly only outcome probabilities into properties of the postulated particle (of one particle). But of course, this does not solve any problem, it doesn't help restore the relation with the result of an experiment. The difference between that superposed state of a particle and the single outcome of an experiment (which is according to Dirac what above all must be explained since it is actually the observation of the particle) is still in need of an explanation. And so, the "disturbance" postulated earlier makes an entry, trying to provide the inevitably missing explanation and creating the famous "collapse" of the wave function:

> "When we make the photon meet a tourmaline crystal, we are subjecting it to an observation. We are observing whether it is polarized parallel or perpendicular to the optic axis. The effect of making this observation is to force the photon entirely into the state of parallel or entirely into the state of perpendicular polarization. It has to make a sudden jump from being partly in each of these two states to being entirely in one or other of them." [**?**, p. 7].

The collapse of the quantum superposition of states does not emerge from the formalism, nor is observed in the experiments themselves, it is the result of the dogmatic presupposition of an atomistic metaphysics and of the way in which it was combined with positivism. Let us briefly summarize what we have read: Dirac took an example related to the polarization of light, and he posed a peculiar question: how to fit this within atomism? From that attempt to explain everything in terms of particles (and not from experiments or from the formalism) we have seen how he dogmatized his positivism by identifying the single outcome directly with a particle, how the probabilistic interpretation of QM was proposed, and how the collapse was then necessarily introduced in order to bridge the gap between an intensive representation and a binary one. All those hypotheses come originally from atomist presuppositions, and none of them come directly from the quantum formalism or phenomena, nor they are able to coherently relate to quantum mechanics. They are created problems that unfortunately have concentrated the attention of philosophers and physicists for decades. Who dares to say that atomism in quantum mechanics is "just a way of talking"?

6 Physical Concepts and Observations

The combination of Bohr's ideas with the positivistic understanding of scientific theories created a paradoxical situation which is still present in the thought of physicists and philosophers of science of the 21st Century as they engage with QM: the articulation of atomist metaphysics with anti-metaphysical positivism. Regardless of the fact that there was no clear indication of them in the mathematical formalism of the theory, the reference to quantum particles remained as a necessary constituent of the quantum discourse, while at the same time all other conceptual endeavors were cast aside as unnecessary. It is in this strange manner, and quite paradoxically, that atomism was saved in QM by its worst enemy. The positivist *Zeitgeist* of the 20th Century, which was in fact based on the very denial of metaphysical representations, kept using atomist metaphysics as an unavoidable "common sense" discourse. Positivism didn't actually evacuate metaphysics from it's fundamental role in the constitution of physical theories, but instead helped crystalize one metaphysics in particular as an unavoidable given, rendering —at the same time— the conditions for its critical analysis impossible. Thus, while atomism was accepted without critical analysis, as a mandatory starting point, positivism then proceeded to leave behind all other metaphysical endeavors —which could be critical to that atomistic representation— considered now as stories about that which could not be observed. Since then, most philosophers interested in quantum physics have accepted a secondary role and have occupied themselves in producing and/or defending mere appearances: they create narratives, "interpretations" of QM —with no influence over the theory itself— that keep multiplying, creating by their growing numbers an absurd situation Adan Cabello has termed a "map of madness" [**?**]. But regardless of the many interpretations, there is anyhow a common metaphysical discourse accepted by both physicists and philosophers which is still today, however unconscious, a classical atomistic one. Funny as it may seem, the reference of QM to a microscopic realm constituted by elementary particles has helped to support the anti-metaphysical program of empirical science which presupposes that theories are developed from the empirically *given.* The belief that the standard account of QM is free from metaphysical commitments is a way of engaging, consciously or not, in dogmatism. *Dogmatism*, in its Kantian definition, is the assumption of a metaphysical representation without its critique, without engaging in its justification —exactly what happens today with atomism in quantum theory. And, as we said, what is especially paradoxical and symptomatical is that, at the same time, it is argued that metaphysics is just a story about the unobserved, that it has no fundamental role whatsoever in scientific theories. It is a contradictory combination of metaphysical dogmatism with an anti-metaphysical stance, a "fictionalist" creed.

But is this all that bad? Are those atomistic presuppositions really an obstacle? Let's get back to our original question, as it is formulated in the title of this work: is atomism, as it is generally claimed, just an innocent "way of talking" with no further consequences? Or is it that obstacle that Mach pointed out and that taints our thoughts and observations, that a priori determines what we are able to conceive, whether we want it or not? We can go back even before quantum physics to find an answer to this question. Already in 1844, Michael Faraday pointed out that

> "the word *atom*, which can never be used without involving much that is purely hypothetical, is often intended to be used to express a simple fact; but good as the intention is, I have not yet found a mind that did habitually separate it from its accompanying temptations" [**?**, p. 220].

Decades later, Schrödinger had a similar diagnose:

> "We have taken over from previous theory the idea of a particle and all the technical language concerning it. This idea is inadequate. It constantly drives our mind to ask information which has obviously no significance" [12, p. 188]

In fact, regardless of the triumph of the Bohrian-positivist understanding of "empirical" science according to which physical theories are derived from observations —i.e., unproblematic givens of "common sense" classical experience— and conceptual schemes are merely "ways of talking", fictional stories about an un-observable realm, most of the main figures involved in the creation of QM were quite aware that concepts are —in physics and in science in general— far from being just part of stories or narratives. Influenced by modern or by ancient philosophy, Einstein, Heisenberg and Pauli were very insistent in the fundamental role concepts played within scientific theories. An enthusiastic reader of modern philosophy, Einstein made reference, as he tackled this question, to Hume and Kant:

> "From Hume Kant had learned that there are concepts (as, for example, that of causal connection), which play a dominating role in our thinking, and which, nevertheless, can not be deduced by means of a logical process from the empirically given (a fact which several empiricists recognize, it is true, but seem always again to forget). What justifies the use of such concepts? Suppose he had replied in this sense: Thinking is necessary in order to understand the empirically given, *and concepts and 'categories' are necessary as indispensable elements of thinking.*" [**?**, p. 678] (emphasis in the original)

It is this same point which Heisenberg [**?**, p. 264] himself would stress in the later years of his career by recalling his conversations with Einstein and the claim that "it is only the theory which decides what can be observed" for "only with the help of correct concepts can we really know what has been observed." As he stressed in his characterization of theories as "closed theories", apart from the quantitative representation provided by mathematical formalisms, it should be recognized that physical understanding possesses also an intrinsically conceptual component. A young Wolfgang Pauli, interested like Heisenberg in ancient Greek philosophy, would explain to him during a conversation in 1921 exactly this essential aspect of scientific understanding:

> "knowledge cannot be gained by understanding an isolated phenomenon or a single group of phenomena, even if one discovers some order in them. It comes from the recognition that a wealth of experiential facts are interconnected and can therefore be reduced to a common principle. [...] 'Understanding' probably means nothing more than having whatever ideas and concepts are needed to recognize that a great many different phenomena are part of coherent whole. Our mind becomes less puzzled once we have recognized that a special, apparently confused situation is merely a special case of something wider, that as a result it can be formulated much more simply. The reduction of a colorful variety of phenomena to a general and simple principle, or, as the Greeks would have put it, the reduction of the many to the one, is precisely what we mean by 'understanding'. The ability to predict is often the consequence of understanding, of having the right concepts, but is not identical with 'understanding'." [**?**, p. 63]

But while adequate concepts are essential in order to properly understand what has been actually observed, inadequate concepts produce exactly the opposite effect. Their inadequate application —to the analysis of the mathematical formalism or the phenomena in a given experimental situation— produces confusions and misunderstandings which generate not only obstacles but also severe misdirections in the accomplishment of a consistent, coherent and unified representation. This is obvious from the fact that the application and use of physical concepts within the analysis of a given situation leads questioning in a specific direction. It is obviously not the same if within the analysis of a given phenomenon we presuppose that the explanation of its cause is due to the entity A or to the entity B. While the entity A will lead the analysis in one direction, the entity B will do so in a different one. In this respect, the *ad hoc* introduction of the notion of particle in the context of QM is maybe one of the best examples within science not only of an epistemological obstruction but also of an extremely efficient factory of inadequate problems and debates.

Quantum mechanics, its formalism, describes the evolution of projection operators intensively quantified in a completely deterministic manner. These intensive quantities are what is actually observed in the lab. And this is the reason why QM is incapable to predict with certainty the appearance of single outcomes. It simply does not talk about them, single outcomes can be only regarded as the reflection of an extremely partial and incomplete information about what is actually observed, namely, intensive spectra. But, by assuming atomism, and by identifying the single outcome with a particle, we neglected the intensive quantities the formalism points as invariant, and we disregarded the multiplicity of outcomes (that the theory predicts) as secondary, as the measure of ignorance with respect to the presupposed —but unjustified— reality of quantum particles —which cannot even be represented. Even if someone wishes still to hold on to the positivist focus in the priority of observation, since he considers observations not as a way to verify hypothesis but as what is first and central in a scientific theory, this person, if he is rigorous, would not start at all from particles (this would condemn him from the beginning to a metaphysically dogmatic approach), but "only" from laboratory results, and this would directly lead him to intensities. This is an undeniable historical fact exposed in Heisenberg's development of matrix mechanics which also shows a case of a rigorous positivistic procedure, of what we call here a "methodological positivism", in contrast with the one Dirac unfolds —and that is most common—, which we choose to call a "dogmatic positivism".

7 Final Remarks: Methodological vs Dogmatic Positivism

There's no doubt about it: positivism played a major role in the birth as well as in the subsequent development of quantum physics. And we can in fact separate those two moments of influence. On the one hand, during the end of the 19th Century, and still during the first decades of the 20th, positivism indirectly played a role generating —through Mach's critique of the *a priori* notions of classical physics— the conditions of possibility to address a new (non-classical) experience —opening in this way the door for the birth of QM by Planck and Heisenberg and relativity theory by Einstein. But on the other hand, and shortly afterwards, positivism would have an important role in the establishment of an essentially inconsistent scheme grounded on a restricted, naïve understanding of observation and a dogmatic metaphysical return to atomism. This last influence of positivism determined the fundamental parameters of the standard account of QM and, consequently, the range of questions that define the present discussion.

While Einstein and Heisenberg were able to extract an essential lesson from Mach's positivism, from the necessity of his critical attitude, in order to consider anew the representation of experience beyond the gates of classicality, the positivistic view of scientific theories that would soon become dominant, together with Bohr's work, would allow Dirac to constrain experience to a binary representation of measurement outcomes as elementary particles that also behaved like waves. Einstein's and Heisenberg's use of positivism is what we call a necessary *methodological positivism*, in contrast with Dirac's *dogmatic positivism.* Why "methodological" positivism? Because it takes positivism, or at least part of it —specifically the critical attitude, the attentive mistrust represented by Mach— for a part of the method, as the necessary skeptical work it requires in order to keep observations free from the presuppositions that volatilize them in inadequate concepts, and to advance on solid grounds —and not as a general view of scientific theories. Einstein and Heisenberg were undoubtedly what we call today "realists". However, Mach's positivistic lessons were for them essential. They extracted from positivism a methodological lesson, they turned Mach's critical attitude into a part of their method. They turned positivism into a part of realism. Mach, for Einstein and Heisenberg, is not the answer. Mach is a lesson —an important one but not the only one. That skeptical moment, that methodological positivism, produced for both a new return to phenomena that in fact cleared the way for positive developments no longer burdened by the obligations of classical space-time and atomism. Let us see how.

One of the clearest exemplifications of the richness and importance of methodological positivism, understood as a critical source for the development of theories, can be found in the work of Albert Einstein, who applied Mach's ideas in order to revisit the notion of *simultaneity* in classical mechanics. As he would remark:

> "The concept does not exist for the physicist until he has the possibility of discovering whether or not it is fulfilled in an actual case. We thus require a definition of simultaneity such that this definition supplies us with the method by means of which, in the present case, he can decide by experiment whether or not both the lightning strokes occurred simultaneously. As long as this requirement is not satisfied, I allow myself to be deceived as a physicist (and of course the same applies if I am not a physicist), when I imagine that I am able to attach a meaning to the statement of simultaneity. (I would ask the reader not to proceed farther until he is fully convinced on this point.)" [**?**, p. 26]

From this critical standpoint of positivist analysis Einstein was able to reconsider physical experience beyond the classical constraints imposed by *absolute* space and time exposing —through the empirical invariance of the speed of light— the relativity of temporal intervals with respect to different reference frames. In turn, it was this essential methodological step which allowed him to develop and justify his special theory of relativity in 1905. Two decades later, in 1925, Heisenberg would be able to escape the classical metaphysical representation of physics and advance towards the actual observation of intensive spectral lines in the lab following not only Mach's critical considerations about atomism and space-time but also his observability principle. It is these two moments, the critical one as well as the openness to a new intensive form of experience, which were essential for the development of QM.

Regardless of the essential role and success of the methodological positivist approach applied by both Einstein and Heisenberg in the development of relativity theory and QM respectively, positivism would very soon reestablish the same metaphysical scheme which Mach had fought against through critical analysis just a few decades before. We find in Dirac's axiomatic re-formulation of QM not only a complete abandonment of the critical consideration of experience —common to Einstein's and Heisenberg's developments— but also its restriction through a dogmatic consideration of observability. Indeed, the English engineer and mathematician would impose —as we have discussed in detail above— a limited understanding of observability grounded explicitly on an inconsistent combination of dogmatic metaphysics and empiricism. Thus, instead of accepting the positivist standpoint which had allowed Heisenberg to develop QM in the first place —namely, the intensive nature of quantum experience—, Dirac would claim that what was actually observed in the lab were not intensive patterns but rather single measurement outcomes. It is this particular understanding of observability dogmatically constrained by a binary representation of atoms and measurement outcomes which in turn would require Dirac to introduce —following Bohr's approach— in a completely *ad hoc* manner not only the "collapse" of quantum superpositions but the action of measurement itself —in terms of a "disturbance" between quantum and classical systems— within the axiomatic formulation of the theory itself —turning the theory inconsistent.

It would be this same “projection postulate” created in order to bridge the gap between quantum superpositions and the dogmatic unjustified reference to binary outcomes which, in turn, would give birth to the infamous measurement problem of QM and an endless philosophical debate about how to justify these new quantum jumps in —supposedly— “realist terms”.

Today, almost one century after Dirac’s work became the basis for the production of QM textbooks, both physicists and philosophers have learned to accept —regardless of historical facts— not only that the theory makes reference in probabilistic terms to single measurement outcomes but also that quantum superpositions are incapable of describing what is actually observed in the lab. According to orthodoxy, QM is simply unable to predict with certainty (i.e., probability =1) the appearance of elementary particles exposed as ‘clicks’ in detectors and ‘spots’ in photographic plates. As repeated by both physicists and philosophers this is due to the uncontrollable interaction or disturbance generated between quantum systems and measurement apparatuses. Following the Bohrian complementarity interpretation it is then argued that “the properties of a [quantum] system are different whether you look at them or not” [**?**]. Bohr’s idea that in QM we are not longer spectators but also actors in the great drama of existence has triumphed and as a consequence, it has been accepted that QM simply cannot be understood [**?**]. We have argued in this paper that this result is the direct consequence of a dogmatic metaphysical approach in which the mathematical formalism and experience have been unnecessarily constrained. Contrary to the orthodox claims, there is plenty of space in order to restore an objective-invariant account of the mathematical formalism and experience given we accept the inadequacy of the modern classical representation and develop a completely new conceptual scheme which is essentially grounded on the intensive nature of quanta [**?**, **?**].

References

[1] Béziau, J.-Y., 2014, “Paraconsistent logic and contradictory viewpoint”, to appear in *Revista Brasileira de Filosofia*, 241.

[2] Bohr, N., 1961, *Atomic Theory and the Description of Nature*, Cambridge University Press, Cambridge.

[3] Bohr, N., 1963, *Atomic Physics and Human Knowledge*, Interscience Publishers, New York-London.

[4] Bokulich, A., 2005, “Niels Bohr’s Generalization of Classical Mechanics”, *Foundations of Physics*, **35**, 347-371.

[5] Bokulich, A., 2011, “How scientific models can explain”, *Synthese* **180**, 33-45.

[6] Bokulich, A. & Bokulich, P., 2020, “Bohr’s Correspondence Principle”, *The Stanford Encyclopedia of Philosophy (Fall 2020 Edition)*, E.N. Zalta (ed.), forthcoming. https://plato.stanford.edu/archives/fall2020/entries/bohr-correspondence/.

[7] Brush, S.G., 1968, “Mach and Atomism”, *Synthese*, **18**, 192-215.

[8] Butterfild, J., 2017, interview: *Jeremy Butterfield: What is contextuality?*, (published 3rd of March, 2017) URL: https://www.youtube.com/watch?v=ZJAnixX8T4U

[9] Cabello, A., 2017, “Interpretations of quantum theory: A map of madness”, in *What is Quantum Information?*, pp. 138-143, O. Lombardi, S. Fortin, F. Holik and C. López (eds.), Cambridge University Press, Cambridge.

[10] Carnap, Rudolf, Hans Hahn and Otto Neurath, 1929, *Wissenschaftliche Weltauffassung – Der Wiener Kreis*, Wien: Wolf, partial transl. in Neurath 1973, pp. 299–318, full trans. in Stadler and Uebel 2012, pp. 75–116.

[11] Cordero, N. L., 2005, *Siendo, se es. La tesis de Parménides*, Biblos, Buenos Aires.

[12] Dirac, P. A. M., 1974, *The Principles of Quantum Mechanics* (4th Edition), Oxford University Press, London.

[13] de Ronde, C., 2021, “The Power of Inconsistency in Anti-Realist Realisms about Quantum Mechanics (Or: Lessons on How to Capture and Defeat Smoky Dragons)”, preprint. (quant-ph:2101.00255).

[14] de Ronde, C., 2021, “Werner Heisenberg’s (Intensive-Matrix) Quantum Mechanics or Paul Dirac’s (Binary-Vectorial) Standard Recipe”, preprint.

[15] de Ronde, C. & Massri, C., 2018, “The Logos Categorical Approach to Quantum Mechanics: I. Kochen-Specker Contextuality and Global Intensive Valuations.”, *International Journal of Theoretical Physics*, DOI: 10.1007/s10773-018-3914-0.

[16] de Ronde, C. & Massri, C., 2019, “A New Objective Definition of Quantum Entanglement as Potential Coding of Intensive and Effective Relations”, *Synthese*, DOI: 10.1007/s11229-019-02482-5.

[17] de Ronde, C. & Fernández Mouján, R., 2018, “Epistemological vs. Ontological Relationalism in Quantum Mechanics: Relativism or Realism?”, in *Probing the Meaning of Quantum Mechanics*, pp. 277-318, D. Aerts, M.L. Dalla Chiara, C. de Ronde and D. Krause (Eds.), World Scientific, Singapore.

[18] Einstein, A., 1920, *Relativity. The Special and General Theory*, Henry Holt & Company, New York.

[19] Einstein, A., 1949, “Remarks concerning the essays brought together in this co-operative volume”, in *Albert Einstein. Philosopher-Scientist*, P.A. Schlipp (Eds.), pp. 665-689, MJF Books, New York.

[20] Einstein, A., Podolsky, B. & Rosen, N., 1935, “Can Quantum-Mechanical Description be Considered Complete?”, *Physical Review*, **47**, 777-780.

[21] Feynman, R.P., 1967, *The Character of Physical Law*, Massachusetts Institute of Technology Press, Massachusetts.

[22] Heisenberg, W., 1958, *Physics and Philosophy*, World perspectives, George Allen and Unwin Ltd., London.

[23] Heisenberg, W., 1971, *Physics and Beyond*, Harper & Row, New York.

[24] Heisenberg, W., 1973, “Development of Concepts in the History of Quantum Theory”, in *The Physicist’s Conception of Nature*, pp. 264-275, J. Mehra (Ed.), Reidel, Dordrecht.

[25] Hilgevoord, J. & Uffink, J., 2001, “The Uncertainty Principle", *The Stanford Encyclopedia of Philosophy (Winter 2001 Edition)*, E. N. Zalta (Ed.), http://plato.stanford.edu/archives/win2001/entries/qt-uncertainty/.

[26] Howard, D., 1985, “Einstein on Locality and Separability”, *Studies in History and Philosophy of Science*, **16**, 171-201.

[27] Howard, D, 2010, “Einstein’s Philosophy of Science”, *The Stanford Encyclopedia of Philosophy (Summer 2010 Edition)*, E. N. Zalta (Ed.), http://plato.stanford.edu/archives/sum2010/entries/einstein-philscience/.

[28] Laudan, L., 1981, “Ernst Mach’s Opposition to Atomism”, in *Science and Hypothesis*, Springer, Dordrecht.

[29] Mach, E., 1959, *History and root of the principle of the conservation of energy*, The Open Court Publishing CO., Chicago.

[30] Mach, E., 1970, "The Guiding Principles of My Scientific Theory of Knowledge and Its Reception by My Contemporaries". In *Physical Reality*, edited by S. Toulmin. Harper Torchbooks, New York.

[31] Mach, E., 1890, "The Analysis of sensations. Antimetaphysical", *The Monist*, Vol. 1, No. 1 (October, 1890), pp. 48-68.

[32] Mach, E., 1926, *Knowledge and Error*, D. Reidel, Boston.

[33] Pojman, Paul, “Ernst Mach”, *The Stanford Encyclopedia of Philosophy (Winter 2020 Edition)*, E.N. Zalta (ed.), https://plato.stanford.edu/archives/win2020/entries/ernst-mach.

[34] Schrödinger, E., 1935, “The Present Situation in Quantum Mechanics”, *Naturwiss*, **23**, 807-812. Translated to english in *Quantum Theory and Measurement*, J. A. Wheeler and W. H. Zurek (Eds.), 1983, Princeton University Press, Princeton.

[35] Schrödinger, E., 1935, "Discussion of Probability Relations between Separated Systems", *Mathematical Proceedings of the Cambridge Philosophical Society*, **31**, 555-563.

[36] Schrödinger, E., 1950, "What is an elementary particle?", *Endeavor*, VolIX, N35, July 1950.

[37] Schrödinger, E., *Nature and the Greeks*, Cambridge University Press, Cambridge, 2014.

[38] Von Neumann, J., 1996, *Mathematical Foundations of Quantum Mechanics*, Princeton University Press (12th. edition), Princeton.

[39] Wheeler, J. and Zurek, W. (Eds.) 1983, *Theory and Measurement*, Princeton University Press, Princeton.

[40] Wolchover, N., 2020, "What Is a Particle?", URL: https://www.quantamagazine.org/what-is-a-particle-20201112/