Greek philosophy for quantum physics. The return to the Greeks in the works of Heisenberg, Pauli and Schrödinger.

Raimundo Fernández Mouján

CONICET
Institute of Philosophy "Dr. A. Korn"
Buenos Aires University - Argentina
Center Leo Apostel and Foundations of the Exact Sciences
Brussels Free University - Belgium
E-mail: raifer86@gmail.com

Werner Heisenberg, Erwin Schrödinger and Wolfgang Pauli exhibited in their works a strong and insistent interest in Greek philosophy. And this interest –they claimed— was not at all separated from their investigations into the new quantum theory. Heisenberg directly affirmed that "one could hardly make progress in modern atomic physics without a knowledge of Greek natural philosophy". What does this claim mean? Why do these central figures in the development of quantum mechanics saw the Greeks as their main inspiring source? Why do they took them as a model for contemporary science, even over their modern predecessors of Enlightenment? This work attempts to answer these questions focusing on three main reasons: the revision of atomism, the recasting of the meaning of "understanding" in physics, and the critique of separations in science.

Keywords: Heisenberg, Pauli, Schrödinger, Greek philosophy, quantum mechanics

Never once did it occur to me to consider the science and technology of our times as belonging to a world basically different from that of the philosophy of Pythagoras and Euclid

Werner Heisenberg.

I hope no one still maintains that theories are deduced by strict logical conclusions from laboratory-books, a view which was still quite fashionable in my student days

Wolfgang Pauli.

Introduction

The question, expressed in the title of this work, about the importance or value of Greek philosophy for quantum physics, about the importance of the *oldest* philosophy for the *newest* science, seems perhaps a bit extravagant, maybe far-fetched. This impression is however rapidly dissipated when one reads the works of three of the most important physicists of the early XXth century, and three of the "founders" of the quantum theory. Werner Heisenberg, Erwin Schrödinger and Wolfgang Pauli exhibited a strong and insistent interest in Greek philosophy. And this interest –they claimed— was not at all separated from their investigations into the new quantum theory. The subject of this work can then be paraphrased, for further precision, as the possible answers to the following questions: Why was the revision of Greek philosophy so important for them? Why were Schrödinger, Pauli and Heisenberg so interested in ancient Greek thought while working on the new quantum physics? But even before answering *why*, we can certainly say that they were not wrong in that interest. It will never be a mistake or a waste of time to go back to the ancient Greeks. They will always be able to teach us the art of thinking, the meaning of understanding, and they will once again remind us what a peculiar and prodigious thing this human endeavour of knowledge is. This rediscovery will most probably instill in us a new freedom of thought, while at the same time rendering us loyal to the rigors of that recovered original art of thinking and understanding. "Study the Greeks": that old advice is far from representing a conservative spirit, this as much is proved by the fact that the most innovative among physicists were the ones who saw the necessity to investigate what the Greeks could show them.

These first thoughts, however allusive, already lead us to a first, introductory answer to the questions about the importance of revisiting Greek philosophy for these physicists: the challenges quantum physics had set in front of the physicists from the early XXth century couldn't be tackled with the known tools of classical physics, they needed to recuperate a more flexible –yet always disciplined— way of thinking, and an approach to the

question of understanding nature less burdened by the customs of their immediate scientific context. In order to achieve that, a jump back beyond the habits of modernity and into the lively Greek source, seemed to them a proper means. As Schrödinger puts it: "By the serious attempt to put ourselves back into the intellectual situation of the ancient thinkers (...) we may regain from them their freedom of thought" [11, p. 19].

Only if we approach things in this manner we can understand what, at first sight, seems like a persistent contradiction in the works of physicists like Heisenberg, Pauli and Schrödinger: the relation between the conscience of being faced with the necessity to take a jump forwards, to a new theory radically different from the known physics, and the fact that, in this task, they showed so much interest in what lay so far in the past, in the most ancient scientists of them all, in the source of western science and philosophy. Confronted with the strange indications of the quantum formalism, it may seem that the only thing we can do is to leap forwards into the void, to do something completely and radically new, or to abandon all hope of understanding and turn to instrumentalism. We tend to think that, given the fact that what QM shows us does not fit at all with the image of the physical world developed during the last five centuries, there is no other support or precedent to rely on. This is for instance Bohr's way of thinking, for whom the concepts of classical physics would necessary remain the concepts of physics for all times –and the reality expressed by quantum physics would remain unknowable beyond metaphorical allusions. But the fact is that there are other available associates that can, at least, help shake off some habits of modern thought while remaining faithful to a scientific spirit –and some of the founders of quantum physics understood this. Aware of the apparent oddness of the attempt, Schrödinger tells us that, when speaking about the subjects he later developed in his book *Nature and the Greeks*, he felt the need to explain himself:

> "There was need to explain (...) that in passing the time with narratives about ancient Greek thinkers and with comments on their views I was *not* just following a recently acquired hobby of mine; that it did not mean, from the professional point of view, a waste of time, which ought to be relegated to the hours of leisure; that it was justified by the hope of some gain in understanding modern science and thus *inter alia* also modern physics." [11, p. 3]

Heisenberg, less preoccupied by appearances, goes even further in claiming that "one could hardly make progress in modern atomic physics without

a knowledge of Greek natural philosophy" [8, p. 61]. One hopes, the other is certain, but they both point to the same idea: this "progress", this advancement, the radically *new*, is conditioned or, in any case, assisted, by the *old*, by a knowledge of the original source. Without the ability to pose again questions of principle, to recuperate a broader view of the task of understanding nature, without the ability to shake off some modern presuppositions, gained by the knowledge of the Greeks, it is difficult –they believe— to be able to tackle the new atomic physics. For Pauli, the Greeks also allowed them to acquire a more profound view of the problems they were facing. Problems that seemed entirely new, but that could be in fact related to the great old problems and dilemmas, and therefore placed in a different perspective:

> "The critical scientific spirit however reached its first culmination in classical Hellas. It was there that those contrasts and paradoxes were formulated which also concern us as problems, though in altered form: appearance and reality, being and becoming, the one and the many, sense experience and pure thought, the continuum and the integer, the rational ratio and the irrational number, necessity and purposefulness, causality and chance" [9, p. 140]

As we revise those quotes, we are made aware of the striking contrast between the common views of Schrödinger, Pauli and Heisenberg, and the widely accepted vision today in scientific contexts –and certainly also among philosophers of science—, according to which science, properly speaking, originated in modern times, in the XVIIth century. These physicists from the early XXth century did not see what began in the XVIIth century and was developed over the following centuries as the origin of science, but rather as the origin of the specific parameters of modern science that quantum mechanics, among other developments, was rejecting. Enlightenment, however admirable, was for them the establishment of a certain view of science that had become problematic, and they saw better allies for their task among the ancient Greeks. They found Plato, Pythagoras or Heraclitus more useful than the modern philosophers and physicists. They were insistent critics of the parameters of science established in the XVIIth, XVIIIth and XIXth centuries. In their works they frequently make this contrast explicit, they distinguish between the aspects of science that had their origin in the XVIIth century and that seemed now problematic (the separation of the world in *res extensa* and *res cogitans*, the limiting of natural science to a narrow materialism, the sharp separations among disciplines and faculties,

etc.) and the ancient Greek model, which could help them overcome those obstacles.

Quantum mechanics was born in a critical moment of modernity (that stretches still to our times), it should not surprise us then that the most lucid minds among those involved in the new physics saw the ancient more fruitful and inspiring than the modern. Schrödinger pointed that this critical moment had created a sort of *Zeitgeist* leading him to the Greeks: "Far from following an odd impulse of my own, I had been swept along unwittingly, as happens so often, by a trend of thought rooted somehow in the intellectual situation of our time." [11, p. 14]. This *Zeitgeis*t was expressed in "the inordinately critical situation in which nearly all the fundamental sciences find themselves ever more disconcertingly enveloped" [11, p. 5]. Among those fundamental sciences in crisis, physics of course stood out:

> "The modern development [relativity and quantum mechanics], which those who have brought it to the fore are yet far from really understanding, has intruded into the relatively simple scheme of physics which towards the end of the nineteenth century looked fairly stabilized. This intrusion has, in a way, overthrown what had been built on the foundations laid in the seventeenth century, mainly by Galileo, Huygens and Newton. The very foundations were shaken" [11, p. 17]

Of course, this *Zeitgeist* pushing him to the Greeks arouse other responses as well. Ernst Mach's response is, as Schrödinger reminds us, exemplary: "he recommends a quaint method of getting beyond antiquity, namely to neglect and ignore it" [11, p. 21]. But Pauli, Schrödinger and Heisenberg, unconvinced by Mach's *tabula rasa*, went on to express their interest in Greek philosophy in relation to particular issues, that will be here divided into three. One was the question of *understanding*: they turned to the Greeks to recuperate a broader perspective on what it means to understand nature through science, and they hoped this perspective would allow them new room to maneuver. Another issue leading them to the Greeks was *separation*: they turned to the ancients to try to find a way out of the extremely compartmentalized and separated scientific landscape. And another very different reason to read Greek philosophy was for them related –as we shall see in the first section— not to its role in inspiring the new physics, but to the critical analysis of the basis of modern science, which in fact took much from some Greek philosophers. Schrödinger reminds us that "the thinkers who started to mould modern science did not begin from

scratch. Though they had little to borrow from the earlier centuries of our era, they very truly revived and continued ancient science and philosophy" [11, pp. 17-18]. And this "is a further incentive for us to return once again to an assiduous study of Greek thought. There is not only (...) the hope of unearthing obliterated wisdom, but also of discovering inveterate error at the source" [11, p. 18]. As we shall see right away, the main Greek influence over modern physics, and the one that appeared as most problematic in the XXth century, was atomism.

1. Versions of atomism

Explaining the different motives for the necessary study of the Greeks, Schrödinger distinguished specially two reasons: on one hand, he hopes they can inspire us to reunite what is now separated (philosophy and science) and that shined as a unity among them; but the second reason aims at producing, at the same time, a critical analysis of what turned out to be problematic in the influence of Greek thought over modern physics. Undoubtedly, for Schrödinger, but also for Heisenberg and Pauli, the Greek philosophy that most strongly and effectively informed the basis of modern physical thought and that –given what QM was showing— appeared to them as extremely problematic, was atomism. As usual, among them it is Heisenberg who describes this philosophy best:

> "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" [6, pp. 65-66]

Quite rightly, Heisenberg describes atomism in contrast to Parmenidean philosophy, and shows what, for many among the Greeks, seemed weak about the atomist proposal. Let's say a word about Parmenides to see if we

can better understand Heisenberg's quote. In his poem, Parmenides aims at indicating the way which can lead us to true knowledge, if properly followed. This path is supported by a main certitude, that Parmenides puts in a famously 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 gave privilege to one or several 'elements' or substances as origin and foundation of nature (of which they primordially predicated being), or dedicated their thought to decipher the hidden order that governs reality (the case of Heraclitus), Parmenides starts by reflecting on a previous, humbler truth: any 'element' we may choose, any 'order', anything of any nature, must be, first, something that is, must share being. The simple yet universal, all-encompassing *fact of being* (as Néstor Cordero puts it [1]) 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. Parmenides' being is not a transcendent principle, is not The Being, The One, but the all-encompassing, irreducible, fact of being –that he will later on in the poem refer to as "what is". But, as we saw, Parmenides thesis adds something else, it also affirms the impossibility of not-being. In fact, it is this part of the thesis that is most extensively and effectively 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 phrases this impossibility in his poem is the one that identies 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 be differences, but there are certainly no ontological separations. It is this impossibility that atomism, as Heisenberg puts it, simply ignores. They take being not in a Parmenidean manner as the irreducible totality of existence, but as a kind of indivisible and extremely small body, many times repeated, as a small substance infinitely combined to construct reality, and so they postulate that not-being (for this construction to happen) must also *be*.

Schrödinger, on his part, is satisfied with a more general description, one

that does not pass through Parmenides, but that aims at rendering explicit 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." [11, p. 64]. But what interests us now is that he later 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." [11, pp. 82-83]

Those who established the basis of modern science found this ancient theory useful, and so it became a fundamental part of the great intellectual edifice they constructed, one that, in many essential aspects, lasts to our days. Heisenberg also describes the historical path through which atomism passed to us, specifically how it was united with the materialistic view that began to take shape in modern times and that, dividing reality in *res extensa* and *res cogitans* (a division to which we will go back later), limited physics 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" [8, p. 12]

Schrödinger too sees this modern atomist worldview as naïve, he claims that the term "atom" has become "a misnomer" [12, p. 183], and states 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. This is not altogether too astonishing, from the above speculations about its origin" [11, p. 87]. The origin Schrödinger refers to is precisely described in his book through a hypothesis that seems, in principle, well supported by the ancient sources. He sees the atomic postulate as originating from a widely known and discussed problem in Greek thought: the problem that arose for the understanding of the physical world from the mathematics of the continuum, mainly, the aspect of its infinite divisibility. This infinite mathematical divisibility, when applied to the understanding of reality, gave way to paradoxes (which were famously developed by Zeno of Elea, who Plato saw in fact as supporting Parmenidean philosophy). And so, a limit to this divisibility –for the physical world— was proposed by atomism as a postulate, and these small indivisible bodies, separated by not-being, were hypothesized. But this patch that once proved so effective seemed to be peeling off in the early XXth century and its weaknesses started to show. 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" [12, p. 188]. But perhaps it is 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" [6, p. 70].

Quantum physics goes much further than 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'" [12, 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 a probability that, in fact, interacts. A new kind of probability, which seems to have physical existence independently of an actual particle, 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" [12, p. 185]. In one instance, trying to provide a new understanding of the reality of this quantum probability, Heisenberg finds a possible ally, among the ancient Greeks, in Aristotle and in his concept of *dynamis* (potency, possibility, capability: all possible translations) as a way of being; a concept modern physics, in its beginnings, ignored to focus only on the characterisation Aristotle did of the actual way of being —which of course in Aristotle's own philosophy could not be separated from the potential way of being, as modern scientists did (see [4]). We should add that this last example is quite representative of the conflict between the relation classical physics established with ancient Greek thought and the relation that quantum physics calls for. Exactly what was excluded, regarded as problematic (Aristotle's concept of potency) by classical physicists, became for those who were developing the quantum theory an interesting possibility; and what for classical physics functioned so well (the principles that for Aristotle defined the formal and actual aspects of entities) became for quantum theory naïve and inadequate parameters.

But apart from his brief speculations about Aristotle's concept of potency, Heisenberg actually attempts to develop a peculiar and radically

different atomist view; a strange, non-materialistic atomism, based on the philosophy of one who, in fact, strongly opposed the atomists: Plato. We can safely say that the *Timaeus* was one of the philosophical works that most deeply influenced Heisenberg since a young age. Heisenberg himself, in *Physics and beyond*, describes his entire intellectual itinerary as different stations in his interpretation of Plato's *Timaeus*[a]. Focusing on this dialogue, where through the character of *Timaeus* it is proposed as plausible that pure geometrical forms are the building blocks of corporeal reality, Heisenberg sees a Plato that develops Pythagoreanism in a new direction, providing a different "atomism" –built up now from mathematical forms and not from material indivisible bodies— that can be better related to quantum mechanics. "Plato was not an atomist; on the contrary, Diogenes Laertius reported that Plato disliked Democritus so much that he wished all his books to be burned. But Plato combined ideas that were near to atomism with the doctrines of the Pythagorean school and the teachings of Empedocles" [6, p. 67]. Pauli shares with Heisenberg this Pythagorean interpretation of Plato: "As a reaction against the (...) atomists, Plato took over into his doctrine of ideas many of the mystical elements of the Pythagoreans. He shares with them his higher valuation of contemplation as compared with ordinary sense experience, and his passionate participation in mathematics, especially in geometry, with its ideal objects." [9, p. 141]. Both Pauli and Heisenberg see Plato as taking much from the Pythagoreans, but steering away from what appeared as mystical associations, which Plato wished rather to gain –without losing what was profound in them— for knowledge, constructing in this way a synthesis that Pauli regards –as we shall later see— as a model.

According to Heisenberg's Platonic atomism, "the smallest parts of matter are not the fundamental Beings, as in the philosophy of Democritus, but are mathematical forms. Here it is quite evident that the form is more important than the substance of which it is the form" [6, p. 69]. Heisenberg, through his peculiar Platonic atomism, is purposely disobeying the modern division between *res extensa* and *res cogitans* which confined physics to the material *res extensa*. And this is not done by incorporating the subject (his choice, his perspective, etc.); he is incorporating real intelligible, formal, elements in the explanation of the physical world as the elements that constitute the inherent order which untiredly unfolds in nature: "atoms are

[a]And he does this in a book of *dialogues*. Both the form and content of this book show the original and profound Platonism of Heisenberg.

not things. This was probably what Plato had tried to say in his *Timaeus*, and, seen in this light, his speculations about regular bodies were beginning to make more sense to me" [7, p. 11]. "Our elementary particles are comparable to the regular bodies of Plato's *Timaeus*. They are the original models, the ideas of matter. [As] Nucleic acid is the idea of the living being. These primitive models determine all subsequent developments. They are representative of the central order." [7, p. 241]. These mathematical forms, the ideas of matter, argues Heisenberg, should not however be interpreted as geometrical forms. This is the limit of the association with Plato:

> "modern physics takes a definite stand against the materialism of Democritus and for Plato and the Pythagoreans. The elementary particles are certainly not eternal and indestructible units of matter, they can actually be transformed into each other. (...) But the resemblance of the modern views to those of Plato and the Pythagoreans can be carried somewhat further. The elementary particles in Plato's *Timaeus* are finally not substance but mathematical forms. (...) in modern quantum theory there can be no doubt that the elementary particles will finally also be mathematical forms, but of a much more complicated nature. (...) The constant element in physics since Newton is not a configuration or a geometrical form, but a dynamic law. The equation of motion holds at all times, it is in this sense eternal, whereas the geometrical forms, like the orbits, are changing. Therefore, the mathematical forms that represent the elementary particles will be solutions of some eternal law of motion for matter" [6, pp. 71-72].

To further clarify the nature of these mathematical forms, it is useful to introduce another ancient Greek philosopher that Heisenberg sees as capable of inspiring an understanding of quantum mechanics: Heraclitus. Heisenberg repeats the traditional –yet highly questionable— interpretation of Heraclitus as a philosopher that, as some of his contemporaries, chose an "element" as origin and fundament of reality. In his case, this element is fire: "He regarded that which moves, the fire, as the basic element." [6, p. 62]. Heisenberg finds that what Heraclitus says about fire as the basic, transformable element, can now be applied to energy: "the views of modern physics are in this respect very close to those of Heraclitus if one interprets his element fire as meaning energy. Energy is in fact that which moves; it may be called the primary cause of all change, and energy can be transformed into matter or heat or light." [6, pp. 71].

With the aim of reuniting these two Greek influences, Heisenberg theorizes the "elementary particles" –now thought of as mathematical forms— as formal stationary conditions of this same Heraclitean "stuff", as the elements of that central order (the dynamical law) that inform this basic energy/matter seen in analogy with Heraclitus fire:

> "This state of affairs is best described by saying that all particles are basically nothing but different stationary states of one and the same stuff. Thus even the three basic building-stones [protons, neutrons and electrons] have become reduced to a single one. There is only one kind of matter but it can exist in different discrete stationary conditions. Some of these conditions, i.e., protons, neutrons and electrons, are stable while many others are unstable" [8, p. 46].

As interesting as this Platonic atomism may seem, one can't help but to wonder why the insistence on developing an atomist view. Why does this obligation persist when there is in fact nothing left to support it? Why not leave atomism aside altogether? It is Schrödinger who finds an explanation for this fixation on atomism:

> "atomism has proved infinitely fruitful. Yet the more one thinks of it, the less can one help wondering to what extent it is a true theory. Is it really founded exclusively on the actual objective structure of 'the real world around us'? Is it not in an important way conditioned by the nature of human understanding—what Kant would have called 'a priori'?" [11, p. 88].

This worldview that seemed to describe the fundamental nature of physical reality started to appear –at least for Schrödinger— rather as a presupposition that constantly and inadvertently conditioned our way of perceiving the world –and one that was most inadequate. To follow the association with Kant's terminology, we can say that atomism appeared now also as dogmatism, as a metaphysical presupposition assumed without criticism. Criticism seemed then to be in order, a critical analysis of the worldview that determined the parameters of physical understanding. So why do we still today hear with such certitude that quantum mechanics talks about elementary particles? Because, for the most part, this critical task was prevented by the influence of Bohr and of positivist philosophy on physics and philosophy of science. The critical analysis of classical concepts and the development of different systems of concepts for this new physical theory was limited by Bohr, who claimed that the only language for physics could be

the language of classical physics. At the same time, positivist philosophy evacuated metaphysics from its fundamental role in scientific theories, and turned it into just a mere storytelling one can –mostly inconsequentially— add, if one desires to do so, to an already functional, empirically adequate theory. So, in this way, atomism, instead of being the object of that criticism that Schrödinger alluded to, was crystalized, in a dogmatic manner, as a basic presupposition not to be questioned again and, at the same time, all other conceptual endeavours –which could be critical of that presupposition— were cast away or reduced to mere storytelling. One inadequate worldview was thus installed as a basic common-sense presupposition, and the –truly fundamental— intellectual endeavour which could favour criticism of that worldview and which could give rise to other possibilities, was reduced to inconsequential narratives. So physicists today claim to the general public that quantum mechanics talks about small elementary particles. Faced with interested questioning they will admit that these are not really small determined particles, but strange "quantum" particles, of which little can they say, and, ultimately, they will claim that, in any case, this talk of elementary particles is really just a "way of talking" we unimportantly adhere to an already empirically adequate theory. But actually, as Einstein insisted, "It is the theory which decides what we can observe" [7, p. 63]. Atomism is for physics not only –as we carelessly claim— just "a way of talking", but more profoundly, a way of thinking, imagining and even perceiving, of which we are many times unaware. This presupposed worldview is, as Schrödinger points out, the source of many of our missteps. It still makes us see what we are in fact not seeing (a particle when a "click" happens in a detector), it makes us ask the wrong questions, and forces us to give widely inadequate answers to those already problematic questions. The critical analysis that Schrödinger demands on the influence of certain aspects of Greek philosophy that appeared at the beginning of the XXth century as problematic –aspects that, through their reinterpretation in modernity, became a truly fundamental part of physical thought— remains still, for a great part, to be done. This is certainly one of the reasons why the task of investigating Greek philosophy for the sake of our own contemporary scientific theories has not grown old yet.

2. Revisiting *understanding*

Schrödinger writes: "the present crisis in modern basic science points to the necessity of revising its foundations" [11, p. 18]. It was not just a matter of filling some remaining gaps. They knew they were not faced only with new

discoveries that could help complete the mosaic of modern physics. They were faced, on the contrary, with the evidence of a complete disconnection between what was being developed in quantum physics and the previous theoretical parameters as they were expressed not only in explicit scientific theories, but also –as we have seen with the example of atomism— in the presupposed worldview that gave sense to the perceived physical phenomena. For there to be understanding of the quantum phenomena, for them to be able to do physical science faced with these new developments, they were obligated to revise, rethink, the fundamental parameters of modern science. They had to ask again what doing physics meant and entailed, they had to take a look at the conditions –if they existed— of the human understanding of nature. The available modern answers were no longer enough. In all of these physicists we see this awareness: they take as a central matter they analyze, discuss, tackle, the question of what "understanding" means in physics. And in order to do that, they often turn to the Greeks. Of course, by that time there exists at their disposal a quite practical response to this question, an easy way out: the positivist renounce, the rejection of the possibility of understanding nature, and the redefinition of science as a merely coherent record of observations.

> "One would in this context have to discuss the questions: what does comprehensibility really mean, and in what sense, if any, does science give explanations? David Hume's (1711-76) great discovery that the relation between cause and effect is not directly observable and enunciates nothing but the regular succession —this fundamental epistemological discovery has led the great physicists, Gustav Kirchhof (1824-87) and Ernst Mach (1838-1916), and others to maintain that natural science does not vouchsafe any explanations, that it aims only at, and is unable to attain to anything but, a complete and (Mach) economical description of the observed facts. This view, in the more elaborate form of philosophical positivism, has been enthusiastically embraced by modern physicists" [11, pp. 90-91].

Before raising the obvious questions that this positivist stance provokes in us (are we to take these "observed facts" as innocent givens? What justifies "economy" as a parameter of this "description"? etc.), let us merely point out a fact that goes often unnoticed: this is an attitude towards knowledge that has as its sources not only modern empiricism, but also ancient Greek thought. We are referring, of course, to sophistry. The Manifesto of

the logical positivists makes this influence explicit: "Everything is accessible to man; and man is the measure of all things. Here is an affinity with the Sophists, not with the Platonists; with the Epicureans, not with the Pythagoreans; with all those who stand for earthly being and the here and now" [3].

Contrary to what its fame indicates, it is not only the taste for controversy what lies behind sophistry, there are some originally sophistic positions —which evidently arose from an opposition to philosophy as it was developed among the first philosophers— that justify their praxis. Some strongly skeptical postures. These are positions that undermined the basis of the attempt to understand nature. For most of them, and specially for two of the greatest among them –Protagoras and Gorgias—, all we have is what we perceive. As radically as the modern empiricists, they discarded knowledge beyond individual perceptions. This aspect of their thought pushed them to relativism. The only remaining text pertaining to Protagoras, which, as we read, the logical positivist quoted in their Manifesto, makes this relativism explicit: "Man is the measure of all things, of the things that are, that they are, of the things that are not, that they are not" [DK 80 B1]. We don't possess more of Protagoras' text but we do have some comments about his philosophy that date back to antiquity, and they all seem to coincide in confirming a relativistic view. According to this stance, there is no such thing as 'a reality of things' —or at least, if there is one, we are not able to grasp it. We can only refer to our own perception. Although he fails to relate this with empiricism and positivism, Schrödinger takes the time to revisit Protagoras: "Protagoras regarded the sense perceptions as the only things that really existed, the only material from which our world-picture is made up. In principle all of them have to pass for equally true" [11, p. 30]. At the same time, since scientific and philosophical discourse could not be knowledge, could not relate to truth, the discursive aspect of these intellectual activities detached, in sophistry, from its function in knowledge and became a matter to be treated independently, and so formal characteristics, as mere coherency and economy, could be justified as ends in their own right.

What perhaps seems odd in this relation between sophistry, modern empiricism and positivism is that, while positivists claimed to enable by their position a scientific progress, the Greek sophists, as well as the British empiricists, concluded more reasonably in skepticism. But maybe the key to understand what this scientific "progress" means can still be found in these older sources, especially in sophistry and in the practical orienta-

tion they gave to scientific and intellectual activity (since true knowledge was discarded). They redirected the goal of discursive argumentations from knowledge to praxis, to the creation of effects. Since, among these effects, truth –if it existed— could not be differentiated from a mere rhetorical effect, it was this effect production, the ability to convince, act, produce changes by these discourses, the true purpose of what could no longer be regarded as knowledge of reality. And if one follows positivism until the end, both in arguments and in history, one arrives also to a practical justification for science: instrumentalism.

In any case, what is certain is that Schrödinger, Pauli, Heisenberg, as well as Einstein, coincide in rejecting the positivist "solution" to the fundamental question of understanding. Einstein, for example, sees the "economic" principle defended by Mach as way too naïve. But the main issue with positivism is, for all of them, its simplistic concept of observation. Heisenberg, Pauli and Einstein will respond to Mach what Kant added to Hume: observation is in itself theoretically laden. Observations cannot be taken as innocent givens. Causality –Kant argued—is surely not directly observable, but it *always* determines observation, and a priori determinations such as causality are what makes experience and objectivity possible. These a priori conditions are, quite fundamentally, part of all observations for all subjects. Mach wished to vanish a priori concepts and stick to observation but, by his blind *tabula rasa* attitude, he actually helped make the concepts that, in fact, determine observation, remain unconscious, unanalysed for many that, still today –willingly or not— continue to follow this naïve empiricism. In a conversation they held in 1925, Einstein explained to Heisenberg –as we commented earlier— that in fact: "It is only the theory which decides what we can observe". Pauli also insists on this matter: "Personally I do not see how it is possible to give a definition of the phenomenon in physics which seeks to isolate the data of perception from rational and ordering principles. It seems to me rather that a separation of this sort is itself already the result of a special critical mental effort which removes the ever-present unconscious and instinctive ingredients of thinking" [9, p. 128].

But there is yet another thing that, according to Schrödinger, positivism leaves unexplained:

> "For even if it be true (as they maintain) that in principle we only observe and register facts and put them into a convenient mnemotechnical arrangement, there are factual relations between our findings in the various, widely distant domains of knowledge,

> and again between them and the most fundamental general notions (as the natural integers 1, 2, 3, 4, ...) , relations so striking and interesting, that for our eventual grasping and registering them the term 'understanding' seems very appropriate" [11, p. 92].

This is of course the expression of one of the original and simplest amazements which always arouse the curiosity inherent in knowledge. These "factual relations" we apprehend between what appears in completely different domains, and between those discoveries and our general notions –a relation that, in fact, allows for the possibility of, among other things, a logical, coherent, even "economical" order to be applied to phenomena, as positivists want—, all of this must be explained. It seems, at least, that there is something like an order developed as well in our own activity as in different domains of reality. What is the nature of this order? Is it an illusion or does it point to an inherent order in nature? This is of course one of Kant's main questions. And his answer is well known: that "order" is originated in subjective –although universal, that is, transcendental— conditions. Transcendental conditions equally determine experience and understanding for every empirical subject. The order of nature (as experience) is for Kant in fact the order of the transcendental subject. Those "factual relations" have their origin in the a priori structure of the transcendental subject. But, unfortunately, Kant's proposal was not a possible solution for the founders of QM. In fact, Kant appeared to be rather part of the problem, and new allies were needed to rethink this fundamental question. The new discoveries of physics violated Kant's a priori conditions, there were in fact experiences which could not be subsumed by the pure concepts of understanding (the categories) and the pure forms of intuition (universal space and time) Kant believed to be universal:

> "The theory of relativity has changed our views on space and time, it has in fact revealed entirely new features of space and time, of which nothing is seen in Kant's a priori forms of pure intuition. The law of causality is no longer applied in quantum theory and the law of conservation of matter is no longer true for the elementary particles" [6, p. 88].

What was previously seen as the conditions for all possible experience and as the parameters of objectivity and understanding now appeared as the limited conditions of a particular worldview that no longer could be taken as universal. Kant's transcendental subject contained the conditions of modern science –it was in fact in part inspired by that science (specially

by Newtonian mechanics)—, but that was no longer enough: "We agree with P. Bernays in no longer regarding the special ideas, which Kant calls synthetic judgements a priori, generally as the pre-conditions of human understanding, but merely as the special pre-conditions of the exact science (and mathematics) of his age" [9, p. 126]. Mach had also pushed for the rejection of Kant's a priori conditions, but without proposing a different solution, a different explanation for what those conditions allowed to understand. He rejected the Kantian a priori determinations as he rejected all possible a priori concepts, aiming to limit the scientific scope only to what is directly observable. But the question of the theoretical determination of observation and the question of those "factual relations" that arouse a sense of understanding nature remained then unanswered. Positivism denied the solution by also denying the problem. This was an attitude that Schrödinger, Heisenberg, Pauli and Einstein thought they could not allow themselves. Faced with the crisis of the modern parameters of knowledge and experience, some of these physicists turned instead, beyond the modern source, to the original source, they jumped back to ancient Greece, in order to rethink scientific understanding.

Heisenberg reconstructs the words of a young Pauli in a conversation they held in 1921, precisely about what "understanding" meant in physics when stripped down to its most essential meaning:

> "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 a 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 (...). The reduction of a colourful 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" [7, p. 33].

Understanding is for Pauli –according to Heisenberg— not just piecing together multiple observations through coherent or economical logical

propositions, it only comes with the recognition –conceptually elaborated— of their common principle, of the reality of the whole their interconnections point to. Understanding is being able to pass from a vision of isolated phenomena to a general reality in which those phenomena show their relation and their meaning (their place). Or, to take Schrödinger's words, it is to pass from the amazed yet uninterpreted vision of "factual relations" in reality to the common principle they express (and that explains their existence). As can be seen exemplified in almost every Platonic dialogue, an isolated individual "understanding" is not truly understanding and cannot help us gain knowledge. It is only through a wider interconnection that is able to point to a common principle, capable of explaining the subsumed experiences, that "understanding" happens, and, with it, knowledge. What those constellations indicate, what those general principles express, that is in fact the goal of knowledge for the Greeks philosophers (and not just what is "directly" observed).

It is also important to add that, according to Heisenberg's Pauli, this can only happen through concepts. There is no understanding without concepts: there is no possible representation of the principles the phenomena point to without concepts, and there is no understanding of the individual phenomena without that representation. Phenomena can be understood only through their principles, and these can only be represented with concepts. As remarked by Heisenberg [8, p. 264]: "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." Of course, we need the ability to pose the right questions, to go against our own suppositions, to identify the decisive relations and arrive at an adequate system of concepts in order for that "reduction" Pauli speaks of to really occur (in Platonic terms: we need to learn the difficult art of dialectics). We cannot force its occurrence under inadequate concepts –as it widely happens today with QM. We cannot produce that unity by mere will, at out pleasure. We cannot force our presuppositions if they are not adequate. The Greeks propose we exercise an equilibrium: the fear of factual errors shouldn't make us renounce general principles for the sake of "exact" although unexplained observations, and, at the same time, the desire for grasping the general should not make us postulate no matter what inadequate principles too fast, or assume a detached mystical attitude. Although difficult, this "reduction" can be produced. And this ability is what Heisenberg refers to as the great heritage of Greek thought:

"What always distinguished Greek thought from that of all other

> peoples was its ability to change the questions it asked into questions of principle and thus to arrive at new points of view, bringing order into the colourful kaleidoscope of experience and making it accessible to human thought. (...) Whoever delves into the philosophy of the Greeks will encounter at every step this ability to pose questions of principle, and thus by reading the Greeks he can become practised in the use of the strongest mental tool produced by western thought" [8, pp. 52-53].

This fruitful strategy we take for granted, this disciplined yet broad, methodical yet artful ability to arrive at the unities manifested in multiples, and to proceed with those principles in a way that enables us to understand the world by ourselves, this is what the Greeks developed and what originated our intellectual attitude and strategy. According to Heisenberg, we are reminded of this each time we aim for the root of things in whatever scientific discipline:

> "Those (...) who (...) wish to get to the root of things in their chosen vocation (...) are bound sooner or later to encounter the sources of antiquity, and their own work can only profit if they have learnt from the Greeks how to discipline their thoughts and how to pose questions of principle" [8, p. 63].

The first expression of this ability directed Greek thinkers to the question of *physis*. This term is generally translated as "nature" and its meaning covers what we refer to when we talk about "the nature of reality" (its essence), as well as what we commonly, broadly and in an extensive way refer to as nature: the reality in which we take part. Nature is, for the first Greek philosophers, something dynamic, changing, which —at the same time— responds to some sort of internal order, substance or formula. This internal order is what they seek to understand. While for Kant reality's *readability*, its order, criteria, came from subjective conditions, for the Greeks those conditions were themselves real beyond the subject (although encompassing also the subject), they were the criteria, the formula, the order inherent to reality, which always rules reality. Those "factual relations" Schrödinger referred to were rather interpreted as signals pointing to an inherent order in reality that philosophy and science aimed to capture. Some of these first philosophers proposed an "element" (or a series of them) from which —and according to which— all reality develops and can be explained. Aristotle calls them the *physikoi*, the physicists or naturalists. Schrödinger also points to the fact that our scientific attitude finds its origin there: these

physikoi, he says, "saw the world as a rather complicated mechanism, acting according to eternal innate laws, which they were curious to find out. This is, of course, the fundamental attitude of science up to this day" [11, p. 57].

Heraclitus redirected the search for the fundament of *physis* no longer to an "element" but to the description of a formula, an internal order that rules *physis*. He allusively described this formula and called it *lógos*. This denomination is very significant for the development of philosophy. Until Heraclitus' use of the word, *lógos* had a meaning almost exclusively related to language: discourse, argumentation, account, even tale. In all of those translations we can see already something that will be essential to all meanings and nuances of *lógos*, even when it doesn't refer to language: a significant combination, a reunion with criterion, a collection with purpose. *Lógos* never means an isolated word, or a meaningless sentence, or dispersed and ineffective ensembles of words. It always refers to a combination that has a reason, that is able to produce an effect or to exhibit a meaning[b]. We now begin to understand why Heraclitus chooses this specific word to name the internal order of *physis*. He sees in nature exactly that: a combination that is not meaningless dispersion, on the contrary, it responds to a formula, a criterion. This double meaning of *lógos* (order of *physis* and human discourse) also expresses for Heraclitus –and this is fundamental— an affinity between human discourse and reality, an affinity that allows for knowledge. Thus, there is a relation between the *lógos* of human beings and the *lógos* of *physis*. It is not a simple task to expose the true *lógos* since, as remarked by Heraclitus, "*physis* loves to hide" [DK 22 B 123], but it is none the less possible: in a particular *lógos* one can "listen" something that exceeds it, that is not only that personal discourse but the *lógos* of *physis*, or, as Heisenberg likes to call it, the central order: "Listening not to me but to the *lógos* it is wise to agree that all things are one" [DK 22 B 50].

Plato develops this further, he renders this *lógos* of *physis* more precise; it is no longer described only in a general manner, as the Heraclitean opposites in the tension of a peculiar harmony, and the path to its knowledge is not so obscurely alluded, but now methodologically developed. What Heraclitus calls the *lógos* of *physis* is for Plato the realm of Ideas. Ideas are the elements (the forms) that populate, constitute, the *lógos* of *physis*, the central order. These Ideas are different, each one is to be found

[b]We follow Néstor Cordero, who thoroughly described in a recent book the transfigurations of the notion of *lógos* in Greek philosophy (see [2])

and known through particular dialectical efforts; these Ideas have different relations among them and with phenomena. They allow for more than a general, allusive, assessment of unity and order in nature, they allow for the different unities, principles, expressed in phenomena to be, each of them, apprehended through methodical efforts, and related among them. In any case, it is this Platonic development, generally known as his "theory of Ideas", that Pauli reinterprets and, with Jungian accents, elaborates on. Specifically, what Pauli seems to emphasize in his reading of Plato is the question of *reminiscence*. For Plato, learning and understanding suppose necessarily a previous presence of Ideas in ourselves. Understanding comes then when, through methodical efforts, we "remember", we recognize in the investigation of the world something that is also essential to our thought. The dialectical endeavour of understanding reality is in Plato, undoubtedly, an effort that asks of us to reject what is only merely personal in our thinking, our opinions and judgments, but in doing so, we encounter that what is truly universal was in fact already in ourselves. An encounter with the universal in ourselves that only occurs through the methodical investigation of reality. As well as in the rest of *physis*, Ideas are expresses in us.

> "With Plato's philosophy in mind, I should therefore like to suggest that the process of understanding nature, as well as the happiness that man feels in understanding, that is, in the conscious realisation of new knowledge, should be interpreted as a correspondence, a coming into congruence of inner images pre-existent in the human psyche with external objects and their behaviour. The bridge (...), which cannot be constructed by pure logic, rests, according to this conception, on a cosmic order independent of our choice –an order distinct from the world of phenomena, embracing psyche as well as physis" [9, p. 125].

That "recognition" Heisenberg remembered in his friend's words is here specified. Understanding nature is the "coming into congruence" of pre-existent images in human psyche and external objects and their behaviour: this seems rather Kantian. But these convergent forms are not originated in the subject, projected by him, are not the property of human conscience, they are not restricted a priori to the limited parameters of modern subjectivity, they come from a greater cosmic order which is expressed as well in human psyche as in *physis*. Understanding is the result of a process by which the forms we read in phenomena –under certain methodically determined conditions— show their affinity, correspondence, with something

we recognize in ourselves, and this is made possible by a cosmic order –an order which is, by this process, made available to our thought. The bridge that enables that recognition in understanding is not made of pure logic, cannot be developed from phenomena by pure logic. Logic alone cannot create that congruence, that moment of understanding (and happiness). Logic cannot create the pre-existent ideas, the forms that enable understanding (it can only suppose and eventually express them). A fundamental cosmic order contains the conditions of that affinity that is actualized in the congruence. For that understanding to occur –for us to recognize in ourselves the forms we perceive— there must exist for Pauli a common medium and origin that enables that real affinity. Understanding is thus the conscient correspondence between the human *lógos* and the *lógos* of *physis*, as it is rediscovered –or "remembered", to put it in Platonic terms— in its expression in phenomena. As Walter Benjamin was also attempting at the same time, Pauli is, in a way, Platonizing Kant, by broadening the conditions of understanding to allow for more than just the modern mechanical experience Kant's a priori determinations justified, and by relocating these conditions outside of the subject: "According to the conception here put forward, the a priori character of Kant's rationally formulated ideas, laid down once for all, is thus transferred to the pre-existent images (archetypes) present and operating outside of consciousness" [9, p. 126].

This "coming into congruence" is the astonishing fact the Greeks were always looking to show and explain, Pythagoreans with the magical correspondence between mathematics and reality, Plato with the experience of reminiscence, Heraclitus with the multiple meanings of *lógos*, etc. And it is by this understanding that theories come into being:

> "Theories come into being through an understanding inspired by empirical material, an understanding which we may best regard, following Plato, as a coming into congruence of internal images with external objects and their behaviour. The possibility of understanding again demonstrates the presence of typical regulatory arrangements, to which man's inner as well as outer world is subject" [9, p. 129].

By this realisation of knowledge, by this process of understanding nature, the typical regulatory arrangements, the ordering principles in *physis*, are demonstrated and represented. It is this central order that theories aim to represent. And it is by this order, as it is manifested in theories, that phenomena become meaningful, that they can be seen as belonging to a

greater whole. They stop being isolated, or, as Plato said, they are saved.

3. Critics of separation

Another important motive for the return to the Greeks is easily found in the works of Heisenberg, Pauli and Schrödinger. They are quite insistent on this one. And perhaps it can be said that this reason subtends the other reasons, that it is expressed or supposed by them, although in different degrees. It is the problem with *separation*. It is –specially for Schrödinger, Heisenberg and Pauli, but also for Einstein— one of the main obstacles for the further development of physics in particular and science in general. A separation that they identified already in the XVIIth century, and that grew with time until it became untenable in the XXth century. Which separation? We actually find in their writings a multiplicity of them –although clearly related—: separation between scientific and speculative knowledge, between scientific and metaphysical attitudes, between experience and theory, between natural sciences and philosophy. Separation expressed also in the objects of knowledge: between *res extensa* and *res cogitans*; as well as more and more (and sharper and sharper) separations between disciplines. It was for instance the growing separation between scientific and philosophical endeavours that had caused, according to Schrödinger, a "grotesque" and childish spectacle he witnessed in the scientific world: "This produces the grotesque phenomenon of scientifically trained, highly competent minds with an unbelievably childlike —undeveloped or atrophied— philosophical outlook" [11, p. 12].

However problematic these separations can be in principle, they became in fact untenable due to the new scientific developments of the XXth century, especially in quantum physics. These authors couldn't help but notice that separations which may had been instrumental and effective for the physics of previous centuries appeared now as burdens. Starting from those separations, maintaining those separations, quantum mechanics was unintelligible. We already encountered some of the problems requiring they undo separations: how to recast the parameters of scientific understanding without revising natural philosophy? How to understand observation beyond modern presuppositions without rediscovering the irreducible and fundamental relation between theory and experiment, between metaphysics and experience? How to transform radically our atomist way at looking at things without critically analysing atomist natural philosophy? How to understand *a probability that interacts* from the point of view of a narrow materialism that only recognizes *res extensa* as physical reality? Einstein,

Schrödinger, Heisenberg and Pauli saw very clearly that the critical analysis of those separations and the effort to overcome them were necessary tasks for the science of their time. The last three of them found, as they worked on the subject, an irreplaceable model for the reunion that they were seeking in the Greeks[c]:

> "We look back along the wall: could we not pull it down, has it always been there? As we scan its windings over hills and vales back in history we behold a land far, far, away at a space of over two thousand years back, where the wall flattens and disappears and the path was not yet split, but was only one. Some of us deem it worthwhile to walk back and see what can be learnt from the alluring primeval unity. Dropping the metaphor, it is my opinion that the philosophy of the ancient Greeks attracts us at this moment, because never before or since, anywhere in the world, has anything like their highly advanced and articulated system of knowledge and speculation been established *without* the fateful division which has hampered us for centuries and has become unendurable in our days" [11, pp. 13-14].

The Greeks were the model for an "advanced and articulated" effort of understanding that did not depend on separations, an uncompartmentalized way of thinking that they needed in order to face the challenges ahead. They were in fact confronted with problems that could not be tackled from the worldview and with the tools that modern physics presented them. They were in need of a broader perspective on the parameters of science and on the nature of physical reality. In their jump back to the Greeks they believed they could recuperate an understanding of the original scientific endeavour (which was one with natural philosophy), riding themselves of the habits and separations that had become common sense in their disciplines, and that were now blocking the way to the development of the new theory. Although developing different aspects of this process of separation in human knowledge, Schrödinger, Heisenberg and Pauli coincide in presenting the Greeks as the model for a non-separated, rigorous yet bold, scientific attitude.

[c]Einstein was more interested in a modern philosopher, one that was especially focused in tackling the problem of separation in our worldview: "I am fascinated by Spinoza's Pantheism. I admire even more his contributions to modern thought. Spinoza is the greatest of modern philosophers because he is the first philosopher who deals with the soul and the body as one, not as two separate things" (cited from [13])

Heisenberg concentrated especially on the critical analysis of the separation that determined for physics –and natural sciences in general— an over-simplified object of knowledge: the *res extensa*, a world defined and limited through a narrow materialism. Nothing beyond the mechanics of independent matter. A determinism of material bodies. A narrow materialism that, according to Heisenberg, enters inevitably into a crisis with the appearance of quantum mechanics. Indeed, how to account, for instance, for quantum probability, or for a principle of indeterminacy, in the context of this extreme form of materialism? He finds the basis of this separation were most clearly and definitely determined by Cartesian philosophy, which he presents in contrast with Greek thought:

> "While ancient Greek philosophy had tried to find order in the infinite variety of things and events by looking for some fundamental unifying principle, Descartes tries to establish the order through some fundamental division" [6, p. 78].

Let us start by the distinction that is made in Heisenberg's words between *finding* order and *establishing* order. It marks a fundamental difference between the Greek and the Cartesian way of looking at things; the difference between apprehending an order seen as existent, and establishing, forging, an order, to better determine and organize our knowledge. The second contrast presented by Heisenberg is between *unifying* and *separating*. While for the Greeks finding order meant understanding what *unifies*, for Descartes the aim was establishing order by being able to *separate*.

> "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" [6, p. 78].

For Heisenberg, Descartes' basic aim was not, as it was the case 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 inherent parameters of nature. The question is different and thus the answer is different, and Descartes' answer is undoubtedly quite a prodigious one; an answer that certainly transformed philosophy: as much as I doubt, I cannot deny that I think –since this doubting is thinking—, and since I am certain that I think, I certainly am (*dubito, cogito, sum*).

But Descartes finds himself locked in a solipsist certainty, 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 functions 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 bases 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" [6, p. 78].

Descartes is, in principle, only certain of himself, 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 –weak— 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, as the bases for knowledge, 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. This is opposite in intention and in origin to the Greek way, which took as its most important object of knowledge the inseparable

interrelation, interdependency, between *physis* and its *lógos*, between the multiplicity of the world and the Ideas that define its essence, between reality and its unifying principles. 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, and for the narrow content of natural science:

> "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" [6, 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 by projecting objectivity and order into the world by means of the subject). The physical world was for the first time established as an object of knowledge completely separated as well from the subject as from God, from the Ideas, the *lógos*, etc. (although this separation will be rejected by later philosophers, as Spinoza for instance, for whom God and nature were synonyms). It is perhaps interesting to get back now, for a brief moment, to Heisenberg's atomism: takings as a starting point his critique of separation, we can perhaps better understand his attempt to reintroduce forms –in his case mathematical forms— as essential elements of physical reality –violating in this way the Cartesian separation, introducing something beyond *res extensa* as the object of physics, and attempting to understand nature from a worldview closer to the one the Greeks had. But, independently of his exploration of a Platonic atomism, what Heisenberg fails to point out –and, as we shall see, this will have a definitive influence on his

conception of quantum physics— is that, while redefining the world as *res extensa*, Descartes is also redefining and narrowing *res cogitans*, thought, which is now –contrary to the Greek or Spinoza's worldview— identified exclusively with subjective conscience. In any case, what is certain is that this separation, with its modern redefinition of the object of physics, is something that, to Heisenberg, quantum mechanics calls into question. This is why, on this matter, Greek thought and not Enlightenment should be for him the inspiring source.

Although he shares some of Heisenberg's historical hypothesis, Pauli is the critic of another separation, between what he calls two types of knowledge or two attitudes towards knowledge, one related to mysticism, to the experience of "oneness", the denial of the world's multiplicity as illusion, and aimed –he argues— at salvation, and the other a scientific attitude, rational and methodical in its means, but "dispassionate" and incapable to see through multiplicity to the fundamental reality of unity. These represent for Pauli two poles, two attitudes presented as opposed for analytical pourposes, but with different relations in different times; sometimes reunited, even mixed, sometimes separated, related only by their mutual exclusion. It is the radical and sharp separation between the two poles that Pauli sees as problematic, the times when we witness an uncritical and superficial mysticism on one hand, and, completely separated, a narrow, short-sighted scientific view on the other. He believes to be living in one of those times.

He starts a conference from the mid 1950's reminding his listeners that many of the fundamental discoveries and bases of our science come from the synthesis of those attitudes, as is the case of the ancient discovery of the "enigmatical" possibility of applying mathematics to nature: "The possibility of mathematical proof, and the possibility of applying mathematics to nature, are fundamental experiences of humanity, which first arose in antiquity. These experiences were at once regarded as enigmatical, superhuman and divine, and contact was made with the religious atmosphere" [9, p. 139]. Pauli believes that "it is the destiny of the occident to keep bringing into connection with each other these two fundamental attitudes" [9, p. 139], to combine the oriental mystical inclination with a western scientific attitude, seeking surely to understand, but without sacrificing "oneness", rather gaining it for understanding, following, as he says, "the Greek spirit". But before entering the Greeks, let us remember first Pauli's characterization of the "mystical" attitude: "Mysticism seeks the unity of all external things and the unity of the inner man with them; this it does by seeking to see through the multiplicity of things as illusory and unreal" [9, p. 139].

Mysticism seeks an experience of unity that reveals multiplicity as illusory and unreal (as well as demonic). And its search is, according to Pauli, a search for salvation:

> "Thorough-going mysticism does not ask 'why?' It asks 'how can man escape the evil, the suffering, of this terrible, menacing universe? How can it be recognised as appearance, how can the ultimate reality, the Brahman, the One (...) be seen?' It is however in keeping with the spirit of Western science –in a certain sense one might say with the Greek spirit— to ask, for instance, 'why is the One mirrored in the Many? What is it that mirrors, and what is mirrored? Why has the One not remained alone?'" [9, p. 139].

The different questions show the transformation the Greeks, this is, philosophy and science in its origins, bring to the more mystical attitude. Their new scientific –or, as Pauli will say, "lucid"— mysticism, that inaugurates western philosophy and science. It is the transformation of a mysteric wisdom into an understanding in which, however, that "oneness" is not lost. The same that is for the mystic the object of a vision, is now, mostly striped from its esoteric aura, conceived and justified as a fundamental object of knowledge; and by this transformation the attitude towards multiplicity also changes: it is not denied, but, on the contrary, explained. The one is not lost, it is rather –more soberly— turned into a matter of understanding. Greek philosophy also seeks, as mysticism according to Pauli, "the unity of all external things and the unity of the inner man with them", but it does so in a different manner, where that unity can be an object of understanding and the goal of a somewhat methodical endeavour. They believe the experience of oneness can be rather its *understanding*. And, in this understanding, the unity is not gained by rejecting reality, by erasing multiplicity. On the contrary, there's no rigorous apprehension of the *one* without the specific *many* it encompasses, and conversely, it is only in the *one* that the *many* is interpreted and understood. It is a rephrasing that changes everything. The questions are no longer "how can I escape this deceiving multiplicity? how can I reject this apparent world to experience the true oneness beyond?" but rather turn into something like "what is the relation (which is not of mutual exclusion) between the one and the many? why is this multiple given? How does this one encompasses and determine this many?". As Heisenberg said, the Greeks rephrased the questions as questions about principles.

If the mystical attitude must be, according to Pauli, synthesized with

the scientific, this also means that the former cannot be completely abandoned. The scientific attitude without the intention to understand what is object of the mystical attitude is insufficient, it cannot even justify and explain the nature of the multiplicity it concentrates on. It is a knowledge that eventually becomes short-sighted, dispersed and narrow, as it had occurred –Pauli believes— to the science of his time: "we can say that at the present time a point has again been reached at which the rationalist outlook has passed its zenith, and is found to be too narrow" [9, p. 147]. Pauli thinks that quantum mechanics, among other recent developments, demands a broadening of this separated scientific attitude, the recasting of what modernity had locked in too narrow limits, approaching and overcoming what lay separated: a too schematic scientific attitude and a too detached and exaggerated mysticism. To develop in further detail this synthesis that he sees as the task of the occident, Pauli names two attempts that were made in this direction, but concentrates rather on one of them:

> "Among the attempts that have occurred in the course of history to effect a synthesis of the basic attitudes of science and of mysticism there are two which I would like particularly to stress. One of these originates with Pythagoras in the sixth century B.C., is then carried on by his disciples and developed further by Plato, appearing in late antiquity as Neo-Platonism and Neo-Pythagoreanism. Since much of this philosophy was taken over into early Christian theology, it continues thereafter in persevering association with Christianity, to blossom anew in the Renaissance. It was through (...) a return to Plato's doctrine of knowledge in Galileo's work, and through a partial revival of Pythagorean elements in that of Kepler, that the science of modernity, which we now call classical science, arises in the seventeenth century. After Newton it rapidly separates itself on rational-critical lines from its original mystical elements" [9, p. 140].

As Heisenberg, Pauli also saw Plato in an essential continuity with the Pythagoreans: "Plato (428-348 B. C.) took over into his doctrine of ideas many of the mystical elements of the Pythagoreans. He shares with them his higher valuation of contemplation as compared with ordinary sense experience, and his passionate participation in mathematics, especially in geometry, with its ideal objects" [9, p. 141]. But Pythagoras represented still, according to Pauli, a clear mystical attitude: "He and his disciples founded an expressly mystical doctrine of salvation, which was most intimately tied

up with mathematical thought, and was based on the earlier Babylonian number-mysticism." [9, p. 141]. It is Plato who takes a fundamental step forward:

> "As a further development of Pythagorean teachings Plato's mysticism is a lucid mysticism, in which understanding, in its various degrees, from opinion (*dóxa*) through geometric knowledge (*diánoia*) to the highest knowledge of general and necessary truths (*episteme*) has found its place" [9, p. 142].

In this continuity, it is in Plato that the transformation towards understanding settles, and, above all, that it does so with unequalled precision and awareness. Plato does more than suggesting that what was the object of a mystical approach can be the object of an understanding: he establishes the conditions of that understanding (as well as the mistakes or detours that commonly prevent understanding) and tries to develop the ways that can lead to it. And in that process of understanding he is able also to distinguish and specify its different degrees and modes, depending on their different objects, their distinct languages and capacities to encompass phenomena. What is only *dóxa*? What is *diánoia*? What is truly *episteme* –the knowledge of principles? What relations do they have, what dependencies among them? He even aims at distinguishing among the higher objects of knowledge, developing his theory about Ideas. In Plato we find the highest image of our faculties. In Plato, the mystical and the knowable, the different disciplines, the one and the many, are not separated. And this does not mean that they lie together in an undifferentiated and allusive unity. On the contrary, he is able to distinguish among what is reunited. And, most importantly, he teaches us how to develop the capacity to do it for ourselves.

After Plato, Pauli sees an emphasis on the mystical attitude gaining momentum in the work of the Neoplatonists:

> "the mystical side of Plato's work gradually gave rise to Neo-Platonism, which achieves more or less systematic formulation in Plotinus (204 to 270 A. D.). Here we find the identity of the Good with the comprehensible carried to an extreme, as compared with Plato's own view, and coarsened by the doctrine that matter (hyle) is a simple lack (privatio) of ideas, that it is moreover the embodiment of Evil and that this is therefore a simple privatio boni, a lack of Good, which cannot be the object of conceptual thought" [9, p. 141].

Pauli then jumps over the Middle ages, right to the Renaissance:

> "The Renaissance was an epoch of extraordinary passion, of furor, which in 15th and 16th century Italy broke through the barriers between different human activities, and brought into the most intimate connection things formerly separated, such as empirical observation and mathematics, manual techniques and thought, art and science" [9, p. 143].

This was not –Pauli argues— an epoch of "dispassionate science" [9, p. 143]. Science was not separated from debates about Greek philosophy, from Neoplatonism, not even from mysticism. It is only in the later XVIIth century, as expressed in Descartes' philosophy and Newton's mechanics, that he sees the scientific attitude beginning to take a separate path: "The later more dispassionate seventeenth-century way of looking at things led to Descartes' analytical geometry and to the absolute space of Newton's mechanics" [9, p. 144]. This leads, like Heisenberg also pointed out, to a separation of the world-picture, but also to the introduction of separations among different disciplines and faculties: "Among the general characteristic manifestation of the seventeenth century is the re-establishment of new boundaries between single disciplines and faculties, and the splitting of the world-picture" [9, pp. 144-145]. That path, Pauli believes, had found its limits and called for a renewed synthesis that would allow us to recast our relationship to knowledge. But how to answer that call? How to approach the poles? How to recuperate that original, broader, way of understanding nature?

> "I believe that there is no other course for anyone for whom narrow rationalism has lost its force of conviction, and for whom also the magic of a mystical attitude, experiencing the external world in its crowding multiplicity as illusory, is not effective enough, than to expose himself in one way or another to these accentuated contrast and their conflicts. It is precisely by this means that the scientist can more or less consciously tread a path of inner salvation. Slowly then develop inner images, fantasies or ideas, compensatory to the external situation, which indicate the possibility of a mutual approach of poles in the pairs of opposites" [9, p. 147].

Faced with a "narrow rationalism" on one side, and with the irrational, ineffective "magic of a mystical attitude", Pauli advices us not to escape this situation or to solve it dogmatically, but rather to honestly experience

its conflicts and the limitations of both stances. He pushes us to experience and grasp how one lacks what the other has; how both seem unsatisfying in the end; how they turn superficial when isolated from each other; how both make good points and encompass things we recognize as meaningful but, in the end, remain so evidently narrow. It is important to understand why and how they fail, what they lack, what they have forgotten and, by these experiences, to develop the ideas which can effectively, precisely, lead to the needed synthesis. It is a truly Platonic advice, a dialectical advice. It is the kind of path that Platonic dialogues take, and it is for instance the one an old Parmenides advices a young Socrates to take in one of Plato's later dialogues[d].

Final remarks: Bohr's persuasion

It is puzzling: the developments we just investigated in Heisenberg's and Pauli's works coexist with some other affirmations that enter with the former, quite evidently, in clear and fundamental contradictions. This can only be explained by Niels Bohr's influence. We know, for instance, how those separations we talked about were "resolved" in some places of Heisenberg's and Pauli's works, and it was certainly not in line with the Greek spirit they took as a model. Instead of following his investigation into Greek philosophy as it pointed the way to a more complex and meaningful representation of the world, a world expressing its principles, its inherent meaning, Heisenberg chose frequently –following Bohr— to take the Cartesian concepts, to accept the reduction of the world realized in them, and simply collapse one over the other. Instead of following through with his critical analysis of the basic division and organization of the world in modern thought, instead of taking as a model what he pointed as exemplary in the Greeks, Heisenberg accepted the modern limitation of *res cogitans* to subjectivity and followed Bohr's "synthesis", according to which the subject directly creates physical reality. Faced with what he saw as naïve materialism, instead of following his own diagnostics, he accepted for the most part Bohr's proposal of an empowered relativism that subordinates physical reality to the subject. And contrary to the Platonic spirit, with its higher valuation of our intellectual capacities, Pauli curiously ended up, on some occasions, following Bohr's "solution" of a premature limitation of knowledge. Niels Bohr's power of persuasion will never cease to amaze. He disguised a renounce (the quantum realm is unknowable) as a new heroic breakthrough (the subject creates

[d]the *Parmenides*

physical reality); he simply rephrased the paradoxes that appeared when using classical concepts to represent quantum phenomena by calling them "complementary" –instead of critically analyzing those concepts— and yet somehow convinced many. He drew an arbitrary limit to our knowledge and the limit was incredibly respected. Rather than recasting the conditions of knowledge inspired by the broader Greek view, Pauli and Heisenberg accepted at times, following Bohr, the limitation of the concepts of physics to the concepts of classical physics: "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." [14, p. 7].

It is certainly a perplexing aspect of their works. Heisenberg's Platonic atomism, with the introduction of forms as the real elements of the central order which is constantly determining reality, is very far from Bohr's proposal. Pauli's view about understanding, which take as its fundamental thesis a cosmic order that is expressed as well in *physis* as it is in psyche, seems also incompatible with Bohr's ideas. And yet, they both tended at times to embrace Bohr's turn. Schrödinger himself, even if he can't be accused of being close to Bohr, makes some of the same assumptions. This can be seen directly in some of his interpretations of Greek philosophers, as he projects in their philosophies a modern worldview. This is clear, for instance, in how he reads Parmenides, of whom he says: "The true reality he puts into thought, into the subject of cognizance as we should say. (...) The [real world] (...) resides in the subject, in the fact that it is a subject, capable of thinking, capable of some mental process at least" [11, p. 29]. And it is most especially clear in his final remarks about the "peculiar features" of our scientific view of the world, which he develops on similar lines. We have been thinking quantum mechanics mostly along Bohrian lines for quite some time now, and we still face the same unresolved paradoxes, we still regret our incapacity to complete the theory, we are still unable to represent the reality expressed in quantum physics. Maybe it is not a bad idea to revisit some of the less transited paths taken by those who first developed this theory, when, in search of a wider and flexible yet rigorous understanding of nature, they turned at times for inspiration, even beyond the Enlightenment, to the Greek source.

Acknowledgements

I would like to thank Dr. Christian de Ronde. An important part of what was here developed had its origin in our frequent discussions.

References

1. Cordero, N. L., 2005, *Siendo, se es. La tesis de Parménides*, Biblos, Buenos Aires.
2. Cordero, N. L., 2017, *El descubrimiento de la realidad en la filosofía griega. El origen y las transfiguraciones de la noción de lógos*, Colihue, Buenos Aires.
3. Carnap, H., Hahn, H. and Neurath, O., 1929, "The Scientic Conception of the World: The Vienna Circle", Wissendchaftliche Weltausassung.
4. de Ronde, C., 2017, "Causality and the Modeling of the Measurement Process in Quantum Theory", Disputatio, Vol. IX, No. 47.
5. Diels, H., Kranz, W., 1922, *Die Fragmente der Vorsokratiker*, Berlin Weidmann.
6. Heisenberg, W., 1958, *Physics and Philosophy*, World perspectives, George Allen and Unwin Ltd., London.
7. Heisenberg, W., 1971, *Physics and Beyond*, Harper and Row, New York
8. Heisenberg, W., 1973, *The Physicist's Conception of Natur*e, J. Mehra (Ed.), Reidel, Dordrecht
9. Pauli, W, *Writings on physics and philosophy*, Springer-Verlag Berlin Heidelberg GmbH, Berlin, 1994.
10. Plato, *Diálogos V*, Gredos, Madrid, 2015.
11. Schrödinger, E., *Nature and the Greeks*, Cambridge University Press, Cambridge, 2014.
12. Schrödinger, E., 1950, "What is an elementary particle?", Endeavor, VolIX, N35, July 1950. Reprinted in *Interpreting bodies: Classical and quantum objects in modern physics*, pp. 197-210, Elena Castellani (Ed.),Princeton University Press, Princeton
13. Viereck, G. S., 1930, *Glimpses of the Great*, Macauley, New York, p. 372-373.
14. Wheeler, J, Zurek, W. (eds), 1983, *Theory and Measurement*, Princeton, Princeton University Press.