Aristotle and the Foundation of Quantum Mechanics

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Abstract

The four antinomies of Zeno of Elea, especially Achilles and the tortoise, continue to be provoking issues which not always receive adequate treatment. Aristotle himself used this antinomy to develop his understanding of movement: it is a fluent continuum that he considers to be a whole. The parts, if any, are only potentially present. The claim of quantum mechanics is precisely that: movement is quantized; things move or change in non-reducible steps, the so-called quanta. This view is in contrast to classical mechanics, where small infinitesimal steps are permitted. The objective of the present study is to show the merits of the Aristotelian approach. It is a suitable candidate for providing a philosophical framework for understanding fundamental aspects of quantum mechanics. Especially one may mention the influence of the final state in quantum mechanics, which in philosophical terms relates to the final cause. Like in the work of Aristotle, examples from science are also presented in the present study. They serve to illustrate the philosophical statements. However, in contrast to ancient Greek, the examples now relate to issues which are only fully accessible to the scientifically trained reader. It may, therefore, happen that certain parts in the present study miss clarity for the philosopher and other parts for the scientist. One conclusion, therefore, could be that an open dialogue between scientists and philosophers is needed to get a better understanding of the challenging issues at the cross-road of both disciplines.

Keywords: Aristotle, Quantum Mechanics, metaphysics, continuum, movement

Outline

1. Introduction

There is no doubt that the technological applications of quantum phenomena have an enormous impact on modern society. One may mention the transistor and diode, which are the basic building blocks of Integrated Circuits (electronic chips) and modern solid-state lighting (LED). Besides, there is extreme good agreement between theoretical quantum mechanical calculations and the experimental findings. The fundamental understanding of Quantum Mechanics (QM), however, has not yet resulted in a universally accepted framework [Schlosshauer 2013]. Even now, nearly a century after the introduction of QM, scientists speak about the weirdness of QM, see, e.g. [Mullin 2017]. Others evoke the possibility of a giant or even infinite number of universes, the so-called multiverse approach [Byrne 2008]. In this way, they intend to reconcile the probabilistic character of QM with the demands of logic.

In the present study, an attempt is made to provide a deeper understanding of the fundamentals of QM by proposing a novel philosophical framework. It originates from ideas of Aristotle about movement. For the Greek philosophers, the notion of movement or, more generally, change was central to their philosophical considerations. The Antinomies of Zeno of Elea suggest that movement is missing intelligibility, but for Aristotle, they were instrumental in arriving at a better understanding of their nature. Likewise, QM deals with movement or change. This focus stems from an unexpected phenomenon: motion or change is quantized; it occurs in discrete steps. In classical mechanics, in contrast, small infinitesimal steps are permitted and mathematically treated with differential equations [Del Carril 2018]. The quanta, minima of movement, appear to be indivisible, in theory, and also confirmed by experiments. It is perhaps surprising that the analysis of Aristotle seems to be a suitable philosophical framework for movement in QM. It provides intelligibility for the findings of QM, i.e., quitting at least in part its weirdness.

In the following, the arguments presented are not new. The author could make repeatedly use of the pioneering work of P.H.J. Hoenen, S.J. (1880-1961). Being available only in Dutch [Hoenen 1947], Latin [Hoenen 1936] or Italian [Hoenen 1949], his work is currently mostly unknown to the scientific and philosophical community. Recently [Cardella 2017] used the results of [Hoenen 1949] and proposed a solution of the AT antinomy in line with the present approach.

This study is organized as follows: In the first section after the introduction, the focus is on the Zeno antinomy of Achilles and the tortoise (AT). Modern solutions tend to transform the physical problem into a mathematical one. It is a good starting point, but only a truly metaphysical approach reveals the fundamental insight hidden in this provoking antinomy. For further analysis, certain philosophical concepts need an introduction like the degree of abstraction and, especially, the continuum [Hoenen 1947]. There one may distinguish the static continuum and when time is involved the fluent continuum. Within this framework, it is possible to find a solution for Zeno's antinomy. Also, new light is shed on fundamental aspects of QM.

When dealing with the fluent continuum, its initial and final point needs special attention. The final point of a fluent continuum (a movement) relates in a certain sense with the final cause. In QM, the final point of a movement (final state) obtains special consideration. It is also central in connection with quantum contextuality [Foster 2017] or the role of the observer, see for example [Laloë 2019]. In the discussion of the last section, some conclusions are given emphasizing the need for an adequate metaphysical basis for the understanding of fundamental issues of modern physics.

2. The Antinomy of Zeno with Achilles and the Tortoise

The paradoxes of Zeno of Elea (490-430 BC) continue to attract the attention of philosophers and scientists, see, e.g. [Mazur 2007]. Aristotle refers to the antinomy of AT in his Physics, VI, 9; he writes:

> Zeno's arguments about motion, which cause so much disquietude to those who try to solve the problems that they present, are four in number. The first asserts the non-existence of motion on the ground that that which is in locomotion must arrive at the half-way stage before it arrives at the goal. This we have discussed above.
> The second is the so-called 'Achilles', and it amounts to this, that in a race the quickest runner can never overtake the slowest, since the pursuer must first reach the point whence the pursued started, so that the slower must always hold a lead. This argument is the same in principle as that which depends on bisection, though it differs from it in that the spaces with which we successively have to deal are not divided into halves. The result of the argument is that the slower is not overtaken: but it proceeds along the same lines as the bisection-argument (for in both a division of the space in a certain way leads to the result that the goal is not reached, though the 'Achilles' goes further in that it affirms that even the quickest runner in legendary tradition must fail in his pursuit of the slowest), so that the solution must be the same. Translation [Hardie 2009].

Common sense already is sufficient to be convinced that something is wrong with the argumentation. However, one would like to be able to identify the fault in Zeno’s approach. For further discussion, the particular situation of the antinomy is transferred to an abstract level. Hoenen explains the notion of abstraction and the division of science [Hoenen 1947, p. 107-110] based on Aristotle and Aquinas, see also [De Koninck 1960] and [Kanne 1979]. Aristotle distinguishes three fields of science: natural philosophy (physics), mathematics and metaphysics (natural theology). All three areas may deal with the same situation or phenomenon; distinct is the level of abstraction and the focus. [Elders 1993] gives in detail the further development of the original Aristotelian vision, see also [Bäck 2008] on the division of science. For the solutions to the Zeno antinomy, one may look at all three levels of abstraction: the physical the mathematical and the metaphysical level. Aristotle is arguing on the latter one and takes the opportunity to develop his ideas about movement and change in general. By doing so, he demonstrates that the antinomy can be solved, as the Gedankenexperiment (thought experiment) of Zeno ignores relevant aspects of reality in the physical level. The next section deals with the analysis of Aristotle. By this approach, a route of reasoning is opened, which is in line with the findings of QM: movement is a fluent continuum and has to be considered as a whole, a quantum.

Dealing with the levels of abstraction, one may start with the literal meaning, i.e., the process of drawing off. The question now arises what is stripped-off and what is remaining. Abstraction supposes a manifold of aspects in the being in consideration. In the Aristotelian hylomorphism (see for more detail the next section), one encounters the dual aspects: matter and form. Both are principles of being, not beings on their own. In the course of abstraction, the material aspects are increasingly removed, remaining eventually only the formal aspects. For a discussion of the process of abstraction during the acquisition of knowledge, see [Driessen 2018]. The first major step in abstraction occurs when all material aspects have been stripped off. Only the formal aspects are remaining, including quantitative determinations. Also here, increasing levels of abstraction are possible. As an example, a cylinder of a certain length and diameter may represent a wooden stick. Further abstraction may result in a line with length A. One now enters the realm of geometry or more general, mathematics. Abstracting even the quantitative aspects and allowing for immaterial aspects, one ends at the metaphysical level where only the thing as such is considered.

Searching in literature for a solution for the AT antinomy, one observes that most of the explanations address issues belonging to the mathematical level. Mathematics has made immense progress since the time of Aristotle. Already Descartes [Descartes 1643] demonstrated that even an infinite sum could yield a finite value. In the case of the AT antinomy, one can consider the paths both competitors would go through before Achilles is overtaking the tortoise. Assuming one would divide these paths into infinite line parts one can show mathematically that even an infinite number of these parts would add up to a finite value, likewise also the infinite time parts will do so. However, one knows meanwhile that this mathematical solution is not of relevance for the physical layer. The reason is that events have, according to the Heisenberg uncertainty principle, a minimum extension in space and time (length and duration). The minima are in the order the Planck length and the Planck time, respectively [Callender 2004]. These values are extremely small. Any finite value, however, contradicts the assumptions in the AT antinomy.

[Hoenen 1947, pp 272-275] discusses the solution of Descartes and remarks that Aristotle presents similar reasoning in his Physics VI, 2.

> Hence Zeno's argument makes a false assumption in asserting that it is impossible for a thing to pass over or severally to come in contact with infinite things in a finite time. For there are two senses in which length and time and generally anything continuous are called 'infinite': they are called so either in respect of divisibility or in respect of their extremities. So while a thing in a finite time cannot come in contact with things quantitatively infinite, it can come in contact with things infinite in respect of divisibility [Barnes 1991].

In the above quotation, a new concept enters that needs special attention: anything continuous or with other words, the continuum. In the AT antinomy several continua are involved, namely, the trajectory with a certain distance and duration of Achilles from the starting point up to the finish of the race, and also the trajectory of the Tortoise. Philosophically the continuum is a challenging concept, or with the expression of Leibniz, a labyrinth [Leibniz 2001]. The problems arise when one focusses on the parts of a continuum.

One may consider the most simple continuum, a line with a start- and an endpoint. According to Aristotle and, one may say, also according to common sense, the parts of a continuum have the same characteristics as the whole, only in a reduced form. That means that parts of a line are again line elements with a finite extension. Points may lie on a line, but are not parts of a line. The reason is that something without any extension cannot contribute to something with an extension. A line, therefore, consists not of a set of points defined by a specific condition, e.g., that these points lie on the x-axis between point A and B. Even an infinite number of points will always remain something with zero extension and never will result in a line. A (mathematical) continuum is divisible up to infinitely, and between any two parts, an infinite number of additional parts can be placed. That means that starting with the parts, one can not construct the continuum. The problem is especially severe if the length of the parts involves irrational numbers. For in mathematics, one is not able to add two numbers, one of which is irrational. The reason for this is that one has to employ a numerical approach with inherently restricted accuracy. In [Hoenen 1947, pp 76-98] one finds an extensive analysis of the Aristotelian continuum.

In a study on the Aristotelian continuum [Roeper 2006] observes that modern mathematics holds a different position with regards to the constituent parts of a continuum. In the most simple case, a line, these parts are points without any extension. Roeper writes

> Aristotle’s view has considerable intuitive plausibility. So why did the point conception win out over the Aristotelian conception and form the basis of classical geometry? One reason is metaphysical in character: the view that the parts of a whole are ontologically prior to the whole, combined with the view that an infinite regress of parts (and therefore infinite divisibility of the line), is impossible.

From the preceding, it appears that the solution of the AT antinomy is less straightforward. The solution of the mathematical level does not take account of the fact that there are minima at the physical level. These are the minimal extension in length of the sub-paths of Achilles and the tortoise and the minimal extension in duration. Also, the mathematical level itself needs additional attention as the analysis of the continuum may lead easily to a labyrinth. The next section will be dealing with the solution Aristotle offers for the AT antinomy.

3. Aristotle's view on Zeno's antinomy

3. 1 The parts of a continuum

The analysis of Aristotle, see [Hoenen 1936, 1947 and 1949] is exceeding the mathematical level and involves concepts of metaphysics. The new insight he offers in his analysis is adding a third possibility to a strictly "yes" or "no" in the treatment of reality. In modern times, [Heisenberg 1958] takes up this view by using the term *potentia* in connection with QM, see also [Kastner 2018]. Aristotle already introduced this third possibility when he discovers a metaphysical structure in every material being: matter, and form. This structure is the so-called hylomorphism. The two terms, matter and form, do not refer to elements of reality, beings, on their own, but are principles of beings. They are more than nothing. The philosophical matter is a potential being that can be actualized by a form. Also, the form of exclusively materials beings is not an element of reality. A being becomes a reality when its form is implemented in a suitable matter.

Going back to the continuum, Aristotle considers the continuum as a whole; only the whole is an element of reality. The parts, evidently cannot be actually present in the whole. Otherwise, the whole would not be one, but an aggregate of several things. Of course, in most cases, the continuum is divisible into parts. However, as long as this division is not carried out, the parts are not actually present in the whole, but only potentially. Aristotle explains in Physics, VIII, 263b3:

> Therefore to the question whether it is possible to pass through an infinite number of units either of time or of distance we must reply that in a sense it is and in a sense it is not. If the units are actual, it is not possible: if they are potential, it is possible [Barnes 1991].

Above the example of the mathematical line has been discussed. The conclusion was that the same qualitative features appear after division into parts. A part of a line is a (shorter) line, of an area a (smaller) area, of an iron wire, a short piece of iron wire. What are the boundaries of a continuum? It seems to be something with a lower dimension than the continuum in question. For a line, the boundaries are points, for an area, lines, and for a three-dimensional object, a surface (area). Moreover, the qualitative features and boundaries of the parts have the same characteristics as the boundaries of the whole, but perhaps with less extension.

The question then arises whether there are natural minima of a continuum. Division to infinity is mathematically possible, but in the physical layer, problems occur. The extreme minimum of an iron wire will be the iron atom. Beyond that limit, one obtains something completely different: electrons, protons, and neutrons. These are parts with a completely different nature and cannot be considered as natural minima of an iron wire. Aristotle and his commentators already discussed the issue of natural minima. Thomas Aquinas [Aquinas 1999] explains with precision the difference of division in the mathematical and the physical level (by the way, *physis* is the Greek word for the Latin *natura*):

> Although a body, considered mathematically, is divisible to infinity, the natural body is not divisible to infinity. For in a mathematical body nothing but quantity is considered. And in this there is nothing repugnant to division to infinity. But in a natural body the form also is considered, which form requires a determinate quantity and also other accidents.

How are the minima determined? To do this, one has to deal with the physical level and consider the accidents of the natural body. The iron wire mentioned above, one can divide into parts, invisible to the naked eye: the iron atom. For complex bodies, especially in biology, the situation is different. [Hoenen 1947] uses the story of the dog of Alcibiades to demonstrate that a dog is not divisible into several smaller dogs. When cutting off the tail, one is left with a mutilated dog and its missing tail, see also [Driessen 2015]. That means that for higher level animals like a dog, there is no division possible in parts with the same nature. Each animal is a natural minimum on its own.

3. 2 The fluent continuum

Aristotle now makes a significant step by extending the concept of continuum beyond objects defined with the three spatial coordinates: the static continuum. For this continuum [Hoenen 1936] employs the Latin expression *continuum permanens*. Aristotle adds the time-coordinate and still conserves the general properties of the continuum as described above. The potential parts have the same nature as the whole, the division is perhaps possible, but as long as this has not been carried out, there are actually no parts. This fluent, non-static continuum is called in Latin [Hoenen 1936] *continuum fluens* and, if besides the temporal also spatial coordinates are involved, movement (kinesis by Aristotle).

Like before, in the case of the static continuum, one may now ask about the boundaries of the fluent continuum. For the spatial dimensions, it should not be different from the static continuum, points, lines, or surfaces depending on the dimensions of the continuum. For time or duration, however, there is only a single time dimension. Accordingly, the boundaries are two points in time, the initial and the final time moment. Regarding the parts, made actual by division in time, one finds similar time boundaries.

Dealing with fluent continua has enormous consequences and enables a route to the final solution of the AT antinomy. For this, Aristotle provides now arguments on the metaphysical level. As shown above, and already stated explicitly by Aquinas, the mathematical level –which is using an *a priori* approach- is not able to solve the antinomy. Only considering appropriate metaphysics and taking into account the nature (physics) of the continuum in question one adds up with the complete picture.

In the view of Aristotle, the movements of Achilles and the tortoise are fluent continua. What Zeno is proposing in his Gedankenexperiment is not an accurate picture of reality. Neither Achilles nor the tortoise are running through an infinite number of actual distances; there are no parts in the movement as long as Achilles nor the tortoise is stopping. More importantly, there is no antinomy. The real world situation is according to common sense, that is, Achilles will pass the tortoise at a given moment. What Zeno has obtained with his approach is nevertheless a meaningful result. It contributed that Aristotle could find the conclusion that movement has to be considered as a whole. As will be shown, that is what QM is about in theory and experiment.

What is the natural minimum of the fluent continuum? In analogy with the static continuum where Aristotle and his followers considered a minimum, also here a natural minimum could be expected. Moreover, this minimum one could identify by inspecting the physical layer of the problem. Already in ancient Greek, it had been known that the natural movement of a string in a music instrument is not continuous but discrete with steps related to fixed numbers, such as octave, quint, or quart. In ancient Greek, Pythagoras (570-495 BC) and other philosophers were able to develop a complete music theory based on arithmetic. There is a minimum frequency for a string, the fundamental, and besides this, discrete overtones (harmonics). Sound with frequencies lower than the fundamental one cannot generate. Here one could object that a string could be driven by an external oscillator, and then a continuous band of frequencies below the fundamental would be obtainable. However, these would not be natural frequencies of the string in question.

With the introduction of QM, the situation regarding natural minima of movements changed. There are minima of movement, and there is no means to get around this. Leibniz stated *Natura non facit saltus* (nature does not make jumps) to provide a basis for his work on infinitesimal calculus [Leibniz 1704]. In QM, nature does make jumps; movement is not continuous. In [Del Carril 2018] this point is studied with particular reference to the work of Pascual Jordan. The following quotation from [Jordan 1944] illustrates the new situation encountered in QM.

> The idea of continuity, which attained its mathematical form in differential calculus, is important for the clear understanding of motive processes. We also want to make it clear immediately that this continuity of natural events -*natura non facit saltus*- was already evident in the elementary fact that it was at all possible to speak of a definite trajectory of a moving body. A body cannot reach one place from another by jerks, suddenly disappearing here and emerging there; it must describe a continuous connected path between the two. By why is that necessary? We know from experience that it is always the way, but is there a logical necessity that it cannot be otherwise? These questions are not idly posed: we shall never be able to understand microphysics unless we have carefully examined such questions.

It is worthwhile again to consider the insight of the old Greek philosophers regarding the connection between mathematics and music. According to [Hapern 2014], the founding fathers of QM, de Broglie, and Schrödinger, had harmonics in mind when developing their theories. This coincidence is not so astonishing as mathematically, strings in music instruments and particles in QM are described by sinusoidal functions. In QM these are the famous wave functions.

As mentioned in the introduction, [Hoenen 1936] already discussed Zeno's Antinomy, the solution of Aristotle, and the connection with QM. In the section about *De continuo Fluente*, subsection *De theoria physicae quantorum*, p. 219 he writes:

> From the nature of the movement, one can derive a metaphysical explanation for the modern theory of so-called quanta. This theory states that energy emission (…), especially in elementary agents, occurs according to specific minima. With other words: as physical bodies are not divisible like mathematical bodies but only down to specific minima (atoms), so likewise, the continuous and extensive corporal activity. This change or motion may be infinitely divisible in mathematics, but physically only down to specific minima, the so-called quanta. (…). This metaphysical foundation of the theory of quanta appears in all other metaphysics to be an unsolvable riddle.[1] (Translation from Latin by the author).

Recently also [Cardella 2017] refers to [Hoenen 1949] and confirms his conclusion.

3.3 A few examples from Quantum Mechanics

In the preceding section, the discussion had focussed on the philosophical insight of Aristotle regarding movement. Now it is appropriate to apply the philosophical concepts to phenomena of modern physics. Does the Aristotelian approach contribute to a new understanding of QM? It is a

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[1] Ex hac indole motus potest haberi explicatio metaphysicae theoriae modernae «quantorum» quae dicitur. Haec generaliter loquendo postulat ut emissio energiae (…) saltem in agentibus elementaribus, fiat secundum determinata minima. Aliis verbis: sicut ipsa corpora physica non in infinitum sunt divisibila sicut corpora mathematica, sed tantum usque ad determinate minima (atomos), ita et ipsa *actio* corpórea extensa et continua mathematice quidem erit in infinitum divisibilis, physice autem tantum usque ad determinata minima, quae «quanta» vocantur. (…) Haec fundatio metaphysica theoriae quantorum in omni alia metaphysica videtur esse aenigma insoluble. [Hoenen 1936], p. 219.

challenging endeavor to start this discussion as concepts of two different fields of human knowledge, namely philosophy and natural science, make part of the argumentation.

The first example is the electron with its negative charge and angular momentum, called spin; for more detail, see [Basdevant 2007]. In classical mechanics, an angular momentum relates to a mass rotating around an axis. As the electron is a single point-like particle with no structure, only rotation around its axis could generate the spin. This classical picture, however, is not without contradiction. The spin, therefore, is considered to be a pure quantum effect. The only thing known for sure is the value of the spin: always ½. There are no other values for this specific movement possible, neither in theory nor found in experimental research. That means that the natural minimum of the spinning movement is simultaneously also the maximum. Consequently, there is no means to reduce or enhance the value of the spin of an electron.

The following example relates to the famous double-slit experiment for waves and particles; for an introduction, see Young's Double-Slit Interference in [Libretexts 2019]. It consists of a source for waves or particles and, at a certain distance, a movable detector on a detection screen. In-between a non-transparent plate is located with two parallel slits. There are two pathways possible from source to the detector, as the only option is propagation through one of the slits. With this simple set-up, originally used for light, physicists connect concepts which address the fundamental discussion in QM on the duality of the particle- or otherwise the wave-picture. It appears that particles like electrons, photons, protons, atoms, and molecules sometimes behave also as waves. Particles propagate like little cannon balls, well defined in space and time in a way coined ballistic transport. Waves propagate differently, occupying ample space, and are not closely confined in time. If there is propagation to a common endpoint along different paths, interference occurs for waves and superposition for particles. If principally the path of a particle through a specific slit is known (this is called which-way information) then always ballistic transport is observed, otherwise interference.

If instead of particles, the source in front of the double slit emits waves, an interference pattern would be expected. However, interference of particles instead of ballistic transport is somewhat astonishing. For a discussion of ballistic transport of photons or otherwise, interference, see [Driessen 2007]. In the light of the foregoing section one could make the following analysis: The movement of the particles, emitted by the source (initial point in space and time) and passing through a double-slit and ending at a specific position at the detector (final point in space and time) has to be considered as a whole. Any attempt to obtain more information about the precise path of the particle after emission is dividing the whole of the movement into parts. In this case, "which-way" information would be obtained for the particle. The consequence is that instead of interference (in QM superposition of several paths) one observes ballistic transport.

It may be useful to reproduce an observation of [Laloë 2019] regarding the counterintuitive view in the currently widely accepted Bohr (Copenhagen) picture.

> In Bohr's universe, in the absence of measurement, a general evolution takes place in a continuos and deterministic way according to the Schrödinger equation. But, in the particular case of events involving the interaction between a microscopic quantum system and a setup especially designed to transfer information to a macroscopic observer, an inherent randomness appears in the evolution. These measurement processes are, so to say, considered as "closed bubbles" inserted within this general evolution, closed events extending over a whole region of space-time, from their beginning to their end. They cannot be decomposed into more detailed relativistic events, and are fundamentally characterized by the fact that an intelligent human being is asking to Nature; the outcome is a unique answer, but nondeterministic.

One could say that the evolution in time according to the Schrödinger equation, is relevant for obtaining the probability to detect a particle at a given place and time. Probability is not reality but is related to what could be real *in potentia*. It refers to the Aristotelic third possibility besides real being and non-being: potential being. Schrödinger's equation deals with wavefunctions, and not with objects of reality but allows to obtain specific values for the potential outcome of a measurement. For more and more repetitions of measurements, the potentially and actually measured values are increasingly identical. For a single event, coincidence is a matter of chance.

It is worthwhile to remember that already [Heisenberg 1958] used the term *potentia* in connection with the wavefunction:

> The probability wave of Bohr, Kramers, Slater, however, meant more than that; it meant a tendency for something. It was a quantitative version of the old concept of `potentia' in Aristotelian philosophy. It introduced something standing in the middle between the idea of an event and the actual event, a strange kind of physical reality just in the middle between possibility and reality.

Kastner et al. [Kastner 2018], [Jaeger 2017], and [Sanders 2018] take-up the view of Heisenberg and confirm the actuality of the Aristotelian approach.

Going back to the double-slit experiments with particles, one may consider the apparent weirdness again. Why not accept that there are natural minima for movements and that any inquiry about the moving particle between initial and final state has no meaning. Pascual Jordan [Jordan 1972] has commented on these peculiar situations. Certain questions in physics one may ask which are grammatically correct, but which are meaningless in natural science. He coined his position scientific neo-positivism, for a discussion see [Driessen 2018]. In this concrete example of the double-slit, nature does not provide or contain information about a single particle between the initial and final state. Any attempt to achieve information about the trajectory will change the outcome, and this can be observed experimentally and is also predicted by theory. Going back to the static continuum of the iron wire, it is not astonishing that by dividing one ends up with something different, namely protons, neutrons, and electrons. In a fluent continuum, one may expect similar behavior. By dividing the movement at a double-slit set-up into parts, the character of the movement is changed and, instead of interference, one observes ballistic transport.

Another example is superconductivity, a phenomenon only understandable by QM. In this case, one is considering the movement of charges in objects that could extend several kilometers, for example, superconducting cables. That means that one is exceeding the realm of micro- or nano-science. It is not the place to explain in detail superconductivity; one may look at [Hyperphysics 2017]. Summarizing the standard Bardeen-Cooper-Schriefer (BCS) theory, one could say the following: In conventional metallic conductors, the charge is conducted by electrons. In superconductors, these are electron-pairs, so-called Cooper-pairs. At low enough temperature, a special QM effect can occur, namely Bose-Einstein condensation of these Cooper-pairs (for single, not-paired electrons this is not possible). These charge carriers now are all in the ground state. Once in this state, the Cooper-pairs move without any resistance, superconductivity has been reached.

Why does this happen? The ground state of the Cooper-pairs could be considered the natural minimum of the movement. In the spinning electron, we saw that the ground state, the natural minimum, was the only possible one. In superconductivity, there is besides the ground state an excited state where the Cooper-pair is split into two independent electrons. However, this excited state is only achieved by supplying a minimum of energy; physicists say that there is an 'energy gap' between these two states. At low enough temperatures, there is no way to supply this energy, and the Cooper-pairs remain stable. In ordinary conductors, there are scattering of electrons at impurities and other irregularities of the metal, and the movement of electrons is gradually reduced. In superconductors, none of these irregularities can reduce the movement of the pairs, as these are all in the ground state. Only if enough energy is provided to bridge the gap, the pairs are broken-up and continue with the speed of normal electrons.

One could compare it with a car where the cruise control is set to a certain speed, say 100 km/h. Any disturbance by flies, rabbits, birds, small stones, strong wind, gently slopes will not reduce the speed of the car. Only significant obstacles, like other cars, a wall, large animals or trees, will lead to speed changes or eventually stopping. That is what happens with Cooper-pairs by disturbances below or otherwise above the energy gap.

A particular case of the fluent continuum should be mentioned: time or duration. Aristotle deals with it in his Physics IV. For him, time, like space, is not an object of reality on its own. What is real is the position and duration of real objects or events, extending in space and time. Above, the division of a continuum has already been discussed. It appears that division results in parts which have the same nature. This peculiarity also holds for the fluent continuum. As a consequence, points in time are only accessible as start or finish of a movement or change. The point "now" is not part of reality. Ursula Coope discusses this issue and others regarding time; she writes in [Coope 2005] about "the puzzling claim that Aristotle makes: that the now is like a moving thing."

3. 4 The final point of a movement and the final cause

When dealing with the fluent continuum, the borders in the time domain need special attention. These are the initial and final point of the movement or change. The fluent continuum may be divisible but also here one would expect natural minima. The new insight of QM is confirming the metaphysical analysis based on Aristotle: movement is a whole in which there are natural minima, the quanta. The initial, as well as the final point, characterize the movement. Speaking of a specific (finite) movement -or more generally change- without referring to the initial and final points would be meaningless.

For Aristotle, movement is characterized by the four aspects of causality, the famous four causes. In science, causality seems to focus on the initial point. Hawking, for example, states: *Within the universe, you always explained one event as being caused by some earlier event.* [Hawking 1988], [Driessen 1995]. However, accepting movement as a whole, the final point contributes to the causality in analogy with the initial point. One of the founding fathers of QM, Arnold Sommerfeld, states [Sommerfeld 1930] (translation from German by the author):

> When on occasions I spoke about a new, conditioned causality, it was mathematically founded. For it appears that we have to calculate the emission by a formula, in which the initial and final condition of the atom enters equally and symmetrically. (...) By the way, this is not entirely new. Aristotle considered besides the efficient cause also the final cause, as also Leibniz did. It had not been before the 18th century that today's form of the concept of causality got through and is now without discussion accepted. It says that the event is exclusively determined by the initial state.

There are many examples where this kind of mathematical formula are applied to calculate the probability of movement or change. In photon emission, one may mention Fermi's golden rule, where there is complete symmetry concerning the initial and final state of the atom in question.

An example of light emission of rare-earth ions may illustrate the impact of this view on experiments and technology. Rare-earth ions are small, atom-sized particles not visible to the naked eye nor standard microscopes. They are intensively studied as they allow detailed studies on excitation and subsequent emission of light (photons). For this aim, they are embedded in a transparent medium, like glass or plastic. Once excited to a high energy state, the ion will decay after a characteristic time to its lower energy state. The energy is released by emitting a photon with a characteristic wavelength spectrum. Snoeks et al. studied light emission of rare-earth ions (Erbium) and did detailed experiments and QM calculations based on Fermi's golden rule [Snoeks 1995]. They changed the final state by changing the optical properties of the environment of the Erbium ion in question and could measure the change in decay rate. They obtained complete agreement between experiment and QM calculations with Fermi's golden rule.

If one places these rare-earth ions between two reflectors, i.e., within an optical resonator, something unexpected will happen: the spectral distribution of the emitted photons gets extremely peaked and narrowed. Besides that, the intensity reaches values only limited by the amount of energy supplied to these rare-earth ions. With other words, one is now dealing with a laser. If one follows a photon emitted from a specific ion one observes an unexpected behavior. Already during emission, the photon takes account of the reflectors which it will encounter later on its path. For an example for experiments with lasing of rare-earth ions, see [Yang 2010] with experiments on Neodymium ions.

The two examples given above, deal with optical engineering of the environment of the ion. In both cases, the emission properties of the ion changed substantially. The changes in the environment were not necessarily in the close-by environment of the ion in question. For a laser, for example, the reflector may be placed thousands of wavelengths of the photon away from the ion. A philosopher could remark that by optical engineering, the final state of the emitted photon has changed. Both, the initial and final state, condition the effect, in this case, the photon emission.

Jacques et al. report on a beautiful experiment [Jacques 2007]. It consists of a photon source where after photon emission, the optical set-up is rapidly changed before the photon is arriving at a detector. The results confirm that the arrangement nearby the detector has an impact on the properties of the trajectory of the emitted photon. In this unique experiment, the decision about this arrangement is taken on a very peculiar moment. It was not before the moment that the photon had left the photon source and has gone through a substantial part of its trajectory. Physicists call this a delayed choice experiment.

In the foundation of QM, much emphasis is laid on the observer, who determines the outcome of a QM experiment. One could say the observer is related to the final cause in that sense that he/she determines the final point of movement (or change). In a recent online article of the science writer Brendan Foster one finds a well-written introduction to Quantum Contextuality, *a part of the complicated relationship between observers and observations* [Foster 2017], see also [Laloë 2019]. For our discussion, the following quotation is of particular interest:

> Quantum mechanics doesn't tell us what electrons are doing when we are not observing those values. The electrons and other particles live secret, unknowable lives, as far as we can predict. A theory that tells us more might give us a complete picture of what electrons are doing at all times. It would also tell us the values of things we can measure like momentum or spin, even when we are not trying to measure them.
> Classical Newtonian mechanics is a theory that has these features. Classical particles are like rocks. They have concrete positions and speeds. They have a real story about what they are doing when we don't look at them. Experiments show us the true values of those things.

What are the secret life of electrons and other particles? What would Aristotle say today? Consider a movement from the initial (i) to the final (f) state. This movement is a whole which is potentially divisible into parts. However, being in the realm of QM, we are mostly dealing with natural minima. That means, there is no division of the movement possible. With strong enough causes, of course, the natural minimum could be broken, but then the qualitative characteristics of the movement would have changed. Asking the question about the secret life means that the questioners assume that there are intermediate states, with other words, that the movement actually is divided into parts. For a movement from the initial state (i) to the final state (f) a division in n sub-movements (steps) could be written down as:

1st step	**from**	**initial state (i): starting point**	to	final state (1)
2nd step	from	initial state (2) = final state (1)	to	final state (2)
3rd step	from	initial state (3) = final state (2)	to	final state (3)
--				
final (n) step	from	initial state (n) = final state (n-1)	**to**	**final state (f): final point**

This kind of division works well for pure mathematics and classical Newtonian mechanics, but not in QM. Similar arguments are given above when discussing double-slit experiments. Any attempt to localize the trajectory of the particle from the source to the detector will change the experimental outcome. It appears that in the light of Aristotle's approach and accepting natural minima of movement, QM is losing part of its weirdness. Current ways of thinking, however, are still greatly influenced by the mechanistic view of 19th-century physics. Lord Kelvin expresses this classical view as follows [Kelvin 1884]:

> I can never satisfy myself until I can make a mechanical model of a thing. If I can make a mechanical model, I can understand it.

It is a challenging task to find the correct framework that allows a correct interpretation of the results of modern science. It is perhaps an optimistic view, but a reframed background philosophy in the line of Aristotle could contribute to a better understanding of modern science.

4. Summary and Conclusions

In the preceding, the argumentation followed an ambitious path. Starting with Greek philosophy and accepting the approach of Aristotle, an adequate solution for the antinomy of AT became visible. Aristotle offers a solution and states that the movement of Achilles and the tortoise have to be considered as a whole, a continuum. In this case, this would be a continuum where time is involved, i.e., a fluent continuum. The relation of a continuum to its parts needs particular attention, and Aristotle proposes a solution which is fundamental to his metaphysics. He introduces a subtlety by offering a third alternative for the relation between things and reality. Instead of limiting the choice to a clear to be (actually) real or otherwise not to be real, he considers the third possibility, namely potentially being real. For a continuum, one could say, that there are actually no parts now, but potentially there may be parts after division. In this way he avoids Zeno's antinomy: potentially there may be infinite parts, but Achilles nor the tortoise need to run actually through an infinite number of distances.

Mathematically, there are potentially infinite parts in a movement, but when looking for the physics of the problem, one will find only a limited number of potential parts. By further division, one eventually encounters a natural minimum. At this point QM enters, as in this theory movement is explicitly quantized and natural minima can easily be identified. However, making the step from philosophy to the results of modern fields of physics like QM, severe difficulties may arise for the philosophically trained reader. Aristotle used examples from the science of his time. For a philosopher like him, it was not a real problem to have that knowledge. In modern times, however, the situation has changed as the access to the results of modern science is restricted to the specialist with years of intense study in science. On the other hand, the philosophical background of these scientists exceeds only by exception high-school level.

As shown above, QM confirms the need for considering movement as a whole. This theory identifies the natural minimum of movements. Also, it becomes apparent that in the calculations, the initial and final state enters symmetrically, see, e.g., Fermi's Golden Rule. Mentioning the influence of the final state in the determination of a movement, philosophers immediately remember the famous four causes of Aristotle, especially the final cause. In the literature of the fundamental aspects of QM, often the role of the mysterious 'observer' appears. Why is there a need for him/her? One reason could be that the final state has to be set-up. The choice of this arrangement affects the final measurement and also theoretical calculation. This behavior encountered in nature, is completely missing intelligibility in classical physics.

A final remark refers to the tentative character of this study. One should be aware that the present approach provides only a sketch of the validity of the Aristotelian framework to clarify long-lasting issues of QM. But it is hopefully shown that it is worthwhile to re-think old philosophical concepts and apply them to modern science. For this, a dialogue is needed between scientists and philosophers to connect the knowledge of both disciplines, the natural sciences (Naturwissenschaften) and humanities (Geisteswissenschaften), see also [Rovelli 2018]. Hopefully, this study will stimulate interdisciplinary dialogue.

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