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On the possibility of a *real* reform in current physics: Penrose and twistor theory

Sobre a possibilidade de uma reforma real na física atual: Penrose e a teoria dos twistors

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Abstract

Since the late 1960s, Roger Penrose has had the ambition to develop a new theory that rethinks the foundations of quantum mechanics. His twistor theory aims to carry out this difficult task. Although today the theory is still in development, it is no less true that it is finding more and more followers and its results are beginning to seem not as far-fetched as initially believed. The goal is still far away, but his impetus for wanting to change things is still valid.

Keywords

Quantum physics. Theory of relativity. Twistor theory. Penrose

Resumo

Desde o final da década de 1960, Roger Penrose tem a ambição de desenvolver uma nova teoria que reconsidere os fundamentos da mecânica quântica. A sua teoria dos twistors tenta realizar essa difícil tarefa. Embora hoje esta teoria ainda esteja em desenvolvimento, não é menos verdade que tem encontrado cada vez mais seguidores e os seus resultados começam a parecer menos absurdos do que se acreditava inicialmente. O objetivo ainda está longe, mas seu ímpeto de querer mudar as coisas ainda é válido.

Palavras-chave

Física quântica. Teoria da relatividade. Teoria dos twistors. Penrose.

1. Introduction: Context in which Penrose raises the problem

Quantum mechanics has been in very good health since it laid its foundations back in the first half of the 20th century, with the works of Bohr, Born, Heisenberg, Pauli and company. On very few occasions since then has the possibility been raised that it needs significant change. But is quantum mechanics so infallible that it doesn't require any rethinking?

Roger Penrose has been deeply occupied with this question. This mathematical physicist proposes not only to touch up some fringes of current quantum mechanics, but also intends to undertake a reform that questions its foundations.

Penrose contextualizes this problem in a specific debate, that is, the one that raises the possibility of an artificial intelligence that is like that of the human being. Our author is contrary to this possibility and offers a series of arguments that he develops, above all, in two works, *The Emperor's New Mind* (1989) and *The Shadows of the Mind* (1994).

The first of these works focuses on the explanation of how algorithms work in machines1. Penrose tries to show that the scope of the algorithms, which are responsible for the operation of the machines, is insufficient for them to achieve the same skills as the human mind and consciousness. He does not speak about an inferiority of the machines, because he recognizes (Penrose, 2012: 60-61) their superiority in some aspects; but Penrose defends an irreconcilable difference. His arguments are supported by mathematical and physical examples, although he also delves into topics related to neuroscience.

In the second, although he does not leave aside the task of algorithms in computers, Penrose focuses on an argument that he outlined in the previous book but that he did not develop sufficiently2, that is, the use of Gödel's theorem in favor of his point of view. He spends a whole

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[1] The concept “machine” can be a controversial one, but to avoid such a problem, I clarify that I will refer to it when I talk about computers just as Penrose does.

[2] This is Penrose´s opinion, not mine.

part of the book on this idea (part two of three). In this work he includes arguments based on physics and neuroscience also. The part concerning neuroscience has on this occasion the support of the studies of Stuart Hameroff, with whom Penrose creates a joint theory3.

These works are full of arguments against the possibility of an artificial intelligence acting as a mind and consciousness just like the human; however, the idea underlying both books is the necessity for a reform in current physics. For Penrose it is essential that contemporary physics should be revised from its foundations. His verdict is based on the inability of current physics to give a satisfactory answer to the debate that his works focus on.

The first step he proposes is the most important: return to the deterministic perspective that Einstein proposed. It is widely known that Einstein advocated the idea that natural processes respond in a deterministic way (that is, in a necessary way). This position made him collide head-on with the greatest personalities of the physics community of his time, as happened with Niels Bohr, with whom he starred in intense debates at the famous conferences held in Solvay at the beginning of the 20th century. Despite being defeated in those discussions, Einstein always remained steadfast in his defense of determinism:

> I do not believe at all in the freedom of man in a philosophical sense. We act under external pressures and internal needs. Schopenhauer's phrase: "A man can do what he wants, but he cannot want what he wants," was enough for me from my youth. It has been a comfort to me, both seeing and suffering the hardships of life, and has been an inexhaustible source of tolerance for me. It has relieved that sense of responsibility that can so often become a hindrance, and helped me not to take myself or others too seriously. Thus, I see life with humor (Einstein, 2013: 11).

The word «determinism» does not appear in this text, but one does not have to investigate too much to see that this concept is implicit in what has been exposed, especially when it appeals to necessity to the detriment of freedom, which is flatly denied. This idea, as I say, promptly convinced him and it was something that remained in his intellectual scheme until the end of his life.

Einstein was perfectly aware of the consequences, not only physical, but also metaphysical, brought by quantum theory. This fact was not to his preference, since it implied giving up

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[3] Known as Penrose-Hameroff theory.

the determinism that was so important in his intellectual scheme (and even vital, as can be seen in the quote above). Indeterminism was here to stay and, almost ironically, it did so inevitably. In this well-known quote from a letter that he wrote to his friend Max Born in 1924, we can see Einstein's discomfort with the “new physics”:

> […] Bohr's opinion on radiation is of great interest. But I should not want to be forced into abandoning strict causality without defending it more strongly than I have so far. I find the idea quite intolerable that an electron exposed to radiation chose *of its own free will*, not only its moment of jump off, but also its direction. In that case, I would rather to be a cobbler, or even an employee in a gaming-house, than a physicist. Certainly my attempts to give tangible form to the quanta have foundered again and again, but I am far from giving up hope. And even if it never works there is always that consolation that this lack of success is entirely mine (Born, 1971: 108).

The Einsteinian conception of determinism is extreme, since it continues to conceive natural processes as deterministic despite the fact that the scientific evidence provided by quantum theory, substantially indeterministic (and increasingly stronger), says otherwise. Einstein maintains the idea that if it is impossible for us to predict the outcome of a single measurement, it is because of our own ignorance and not because natural processes are indeterministic.

Returning to Penrose, he is not as clear as Einstein regarding determinism in any of his writings. However, the sympathy that our author professes for Einstein and his ideas is manifest. When Penrose speaks of his deterministic position he does so almost shyly. This is a constant in Penrose's approaches and is due, in my opinion, to the fact that our author prefers to be cautious when he is entering in philosophical debates. This aspect is usually understood as a lack of esteem on the part of Penrose towards these issues because they do not deserve attention, but, as I say, this is far from reality. I think that our author prefers not to position himself in a debate on which he cannot give an expert opinion, precisely because he considers it important. It is more convenient, therefore, to remain in the field of physics in order to substantiate its support for the Einsteinian view of determinism.

Whether their positions fully coincide or not, the truth is that they have very similar features and Penrose is not shy about declaring himself indebted to Einstein in many of his ideas, not only in the field of physics but also in his philosophical stand.

It is precisely the philosophical ideas that place Einstein (and to a certain extent also Penrose[4]) in the perspective of classical physics. This is something curious, because Einstein was one of the greatest contributors to the development of modern physics. Einstein knew of the potential of physics that was making its way, but he was also convinced that it also had limits within it that should not be ignored. Although his task of showing such limitations did not achieve the goal that he expected (something that we can see in the quote above), Penrose finds in that idea of making a change the way to follow. And it is on this Einsteinian idea that our author relies on to begin outlining the reform in current physics that he intends.

2. The weaknesses of current physics

To propose a reform in current physics, it is essential that those aspects that are deficient are exposed. An example of the features of quantum mechanics that did not convince Penrose is that it has the ability to contemplate all possibilities[5]. This is, in fact, one of the strengths of quantum mechanics; however, for Penrose this can take on a negative character. Our author asserts that with this we are not allowed to determine which calculations are possible and which are impossible, since there is no sharp distinction between the different possibilities (Penrose, 1991: 370). Penrose does not mean that in quantum mechanics anything can be possible. Our author is one of the greatest experts in this field today and knows (and acknowledges) the broad and precise explanatory scope of quantum mechanics. His criticism points rather in the direction of limiting the possibilities so that, precisely, there is no risk of implying that anything could be valid.

Another aspect that he highlights is that which consists of the inability of quantum mechanics to offer an adequate description of the environment of the experiments (both mental

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[4] Penrose differs from Einstein, among many other aspects, in that the former wants to carry out the reform in quantum physics within the scheme of this field, while Einstein spent more than thirty years of his life trying to find an alternative to quantum physics, something that, as is known, he did not achieve.

[5] In this point Penrose talks about a very specific characteristic, that is, that of the wave function, which, as is known, has the ability to contemplate all possible options. This is very well reflected in the famous example of Schrödinger's cat thought experiment, which is precisely an example that Penrose likes to return to constantly.

and empirical). Our author recognizes, on the other hand, that this is a real problem and that it concerns any current or future theory, since he understands that trying to approach a complete description of the environment is an impossible task (Penrose, 1991: 370); after all, we cannot have the attributes of Laplace's demon. The universe continues to be tremendously complex and we seem condemned to offer a more or less subjective answer about it.

So why accuse quantum mechanics of a problem that seems to have no solution? Penrose thinks that this problem exists because current theories are based on subjectivist principles[6]. Therefore, the solution would be to abandon that subjectivism that governs scientific theories. But is it possible to achieve a perspective that does not have this nature? Penrose is hopeful that this will be the case, although he acknowledges the difficulty of doing so.

The way in which our author believes that we could depart from subjectivism to obtain different results would be to adopt a deterministic perspective. His proposal is not easy to carry out. In fact, Penrose himself acknowledges the difficulty of leaving everything in the hands of determinism:

> One might try to take the line that the actual evolution is the deterministic **U**, but probabilities arise from the uncertainties involved in knowing what the quantum state of the combined system really is. This would be taking a very 'classical' view about the origin of the probabilities that they all arise from uncertainties in the initial state. One might imagine that tiny differences in the initial state could give rise to enormous differences in the evolution, like the 'chaos' that can occur with classical systems [...]. However, such 'chaos' effects simply cannot occur with **U** by itself, since it is linear: unwanted linear superpositions simply persist forever under **U**! To resolve such a superposition into one alternative or the other something non-linear would be needed, so **U** itself will not do (Penrose, 1991: 371).

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[6] When Penrose speaks of subjectivism he does so in reference to what he understands to be Bohr's perspective. For our author, Bohr is wrong in not granting even a degree of "objective" reality to what quantum mechanics says to us: [...] Bohr seems to have regarded the quantum state of a system (between measurements) as having no actual physical reality, acting merely as a summary of “one's knowledge” conceming that system. But might not different observers have different knowledge of a system, so the wavefunction would seem to be something essentially subjective or “all in the mind of the physicist”? Our marvellously precise physical picture of the world, as developed over many centuries, must not be allowed to evaporate away completely; so Bohr needed to regard the world at the classical level as indeed having an objective reality. Yet there would be no “reality” to the quantum-level states that seem to underlie it all (Penrose, 1989: 280). If Penrose understands or not correctly Bohr´s perspective could be a debate, but it is one that we won´t enter here.

It is therefore necessary to find a non-linear procedure that allows the desired change of focus. This, for Penrose, is a real problem and is perfectly perceptible through the problem of consciousness (this being the main argument of his work!). According to our author, consciousness is not computable and we cannot explain this, precisely, because current physics does not allow it.

Penrose does not have the necessary arrogance to believe that he is the only one who has raised this type of problem from the perspective in which he does so. That is why he recognizes the works of Von Neumann, Wheeler or Wigner, despite the fact that none of them completely convinces him. On the other hand, he does give a little more credence to Everett's theory of many universes or multiple universes. He does not fully subscribe to this particular approach[7], but he has some sympathy for some of its fundamental ideas. The one that most convinces him is the renunciation of the indeterministic process **R**[8] by Everett's theory[9]:

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[7] Penrose does not clearly explain what it is that does not convince him about Everett's theory of multiple universes. What he says is: I do not see why a conscious being need be aware of only "one" of the alternatives in a linear superposition. What is it about consciousness that demands that one cannot be "aware" of that tantalizing linear combination of a dead and a live cat? It seems to me that a theory of consciousness would be needed before the many-worlds view can be squared with what one actually observes. I do not see what relation there is between the "true" (objective) state-vector of the universe and what we are supposed actually to "observe" (Penrose, 1991: 373).

[8] Roughly speaking, the process **R** is what Penrose calls the reduction of the state of a system. We speak about the reduction of the state of a system when the value of the state of that system is determined from among all possible values. This process is indeterministic and is opposed to the **U** process, which occurs through the deterministic Schrödinger equation. These two processes coexist in current physics, but there is a clear inconsistency between them, being irreconcilable when we try to make quantum measurements, and this, according to Penrose, is something that we should change.

[9] In quantum mechanics there is a fundamental problem, that is, the reconciliation between superposition (the ability of quantum particles to be present in several places at the same time) and the determination of what happens in the plane of experience (since it is impossible for us to observe anything like superposition in the macroscopic world). Everett's theory can, somehow, handle this problem. Sticking to the formal plane, what this theory says (broadly speaking, of course), is that superposition states "are just states of the world in which more than one macroscopically definite thing is happening at once" (Wallace, 2010: 5) not in an indeterminate way (as quantum mechanics tells us), but by multiplying this states. In other words, if it is not possible for us to observe something like superposition in experience, it is because the different states unfold and reproduce themselves in different worlds; that is why in this theory it is not necessary to introduce the reduction of the state (that is, the **R** process), since all the possibilities are contemplated with said multiplication of worlds. Of course there are many problems within this theory, such as the fact that these worlds do not interact with each other; or how uneconomical the approach of multiplying worlds is. But in this work we will not stop to analyze the details of this theory since it would distance us from the matter that concerns us.

> [...] Claims have been made that the 'illusion' of **R** can, in some sense, be effectively deduced in this picture, but I do not think that these claims hold up. At the very least, one needs further ingredients to make the scheme work. It seems to me that the many-worlds view introduces a multitude of problems of its own without really touching upon the real puzzles of quantum measurement (Penrose, 1991: 373).

After all, the problem with quantum mechanics is that, although it is suitable for describing processes and solving problems that are impossible for classical physics to tackle, it is no less true that its capacity is not so infallible at the macroscopic level. In fact, in some circumstances classical physics is still more practical and more faithful to the macroscopic realm than quantum theory. In Penrose's consideration, this is a factor that must not be neglected when judging the need for a reform in current physics. The indeterministic and subjective device of **R** cannot be the definitive solution! However, Penrose recognizes that **R** can offer us an objective description of the behavior of a particle, as long as several of them are not involved (Penrose, 1991: 374). The knowledge that **R** provides us, therefore, is inevitably limited and that is why we need to find new alternatives, always taking advantage of what we already have:

> [...] we need to understand the new law in order to see how the quantum world merges with the classical. I believe, also, that we shall need this new law if we are ever to understand minds! For all this we must, I believe, look for new clues (Penrose, 1991: 376).

Penrose is far from giving up, and in each new work he does, he returns to the same defense: current physics is insufficient to continue answering certain questions about nature and therefore needs to be reformed.

3. Reasons why a reform in current physics is not contemplated

But if quantum mechanics requires major reforms, why does there not seem to be a need for it? Is Penrose's position wrong? Knowing how serious Penrose's work is, the scientific community does not unilaterally discredit the Penrosean proposal; however, it is considered risky, since the results of current physics would not allow a reform of the style proposed by our author. But to what extent are Penrose's ideas groundbreaking?

Our author's position belongs to what is known as Quantum Gravity (**QG**), which, in turn, belongs to the Theories of Everything (**TOE**). Like the vast majority of these theories, the one presented by Penrose finds it very difficult to be confirmed, due, obviously, to its novelty. There are those who are less optimistic and think that this lack of confirmation is due to the fact that these types of theories are doomed to failure. As we already know, our author clearly distances himself from this last attitude and thinks that the **QG** path is strictly necessary in order to continue giving answers that are increasingly more precise.

In the specific case of Penrose's theory, a proposal with a plus of originality is advocated, since it suggests a different approach with respect to the relationship between quantum mechanics and general relativity:

> [...] On the one hand, he is firmly convinced of the need to search for that theory and, on the other, he distances himself from the conventional point of view. While most authors suggest that general relativity should be integrated into quantum mechanics, Penrose holds the opposite position: it is quantum mechanics that should be integrated into the theory of general relativity. Simplifying greatly, this position implies that, if the theory of general relativity were extended to include boundary conditions, then it could give an explanation of the quantum phenomena that are seen in singularities and thus encompass the already known quantum phenomena (Herce, 2014: 153).

The question that arises again is: to what extent is it possible to carry out Penrose's claim? This question seems to be a never-ending problem, because if it is argued that the proposal is very far from being implemented, it can be counterargued (as indeed Penrose does) that if it is in such a situation, it is precisely because such a change is needed.

Penrose can be criticized because the solution he presents does not solve the problem that he himself exposes. At the end, this solution involves making a reform in current physics that today does not seem possible. This could bring about the idea that Penrose builds his arguments on the basis of his convictions, rather than according to their applicability in scientific practice. These criticisms, on the other hand, would not be fair, since Penrose does not limit himself to launching arguments based on his beliefs. He himself has developed his own theory, twistor theory, which is in the process of being developed for the future and which has the ambition to be seen as that missing ingredient in current physics. We will see later some of the characteristics of twistor theory.

If Penrose's ideas can be revolutionary for modern physics, why don't they have a wider reach? Appealing to the novelty of his proposal has never been an argument that Penrose has used in his favour, and the truth is that he has not paid much attention to such an issue either, at least until his latest works in which he does develop some concrete ideas.

Our author thinks that the fashion factor within physics is a component that must be taken into account, since ultimately it is obeyed more than it may initially be believed.

Saying that fashion is the only thing that dictates what should or should not be investigated in physics (or in science in general) cannot even be considered an argument, and that is why Penrose clarifies what he means when he grants to fashion a fundamental importance. There are practical aspects, and the contribution to the knowledge of the field is essential for a theory to prosper and be widely studied. However, this condition is not exclusive either. There are other factors and fashion has, according to Penrose, an important weight. Our author exposes this idea with the development of a specific theory, that is, modern string theory.

It is true that Penrose uses the specific case of string theory to explain the importance of fashion, but he also clarifies that this dynamic has occurred throughout history. Our author mentions several examples, such as the theory of the four elements with geometric shapes, widely recognized in Ancient Greece; the astronomical studies of Ptolemy, which constituted the image of the universe for centuries; or the phlogiston theory, which remained in force for more than a century. The success of these theories of nature was not due to a simple acceptance *per se* of the intellectual elites of the time. Behind them there is a complex and elegant lace of mathematics (at least in the first two) that seem to constitute the world around us. However, they all ultimately turned out to be wrong or, to be somewhat more benevolent, less accurate than originally believed. Penrose argues that these theories would not have remained so long on the top of the mountain without this factor of fashion.

There are also examples in which the role of fashion has had an effect, as can be seen with those theories that were abandoned but were rescued over time. The cases that Penrose highlights are William Thomson's theory of atoms as knots, rescued precisely by string theory;

and the Platonic idea of the cosmos as a dodecahedron, which has been revitalized relatively few years ago (2003).

Returning to modern string theory, our author reviews the scope of this theory and the different topics that he can address (supersymmetry, brane worlds, etc.). His intention is to show that string theory, more than explanatory power, enjoys the privilege of being fashionable. And this should not be misunderstood. Penrose does not hesitate to recognize what is positive about string theory, hence he lists it. However, he also wants to show that the results obtained with string theory are not those that were initially expected from it (these results being less extensive).

Now, what are the necessary factors for theories to be fashionable? The simple influence of the scientific community? Penrose is aware that the matter has considerable complexity and does not allow all the weight to fall on the mandate of the scientific community, despite the fact that it is of unquestionable importance. Our author highlights several aspects. As we will see, they all play a very important part in continuing fashion rather than participating in the creation of fashion itself.

The first of these aspects is the most obvious: the explanatory potential of the theory. Although string theory has serious limitations, its breadth is also recognized. The second is the attitude of the new scientific generations, which tend to follow fashionable theories either to defend them or also to try to revolutionize them, thereby perpetuating their continued fashion. The third is the one that concerns the financing part. String theory is, without a doubt, one of the theories that raises the most in terms of research, which gives it a prestige that the others, or at least the vast majority, do not enjoy[10].

Penrose is not trying to disparage current theories or string theory in particular. Our author recognizes the strength and prestige of these theories; however, he finds necessary to

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[10] This fact is something that does not please Penrose, who says: […] It is my own view that the representation of string theory has for many years been excessive. Undoubtedly, there is enough in the theory which is fascinating and well worth continuing development. This is particularly true with regard to its impact on numerous areas of mathematics, where the effect has certainly been very positive. But its stranglehold on developments in fundamental physics has been stultifying, and has in my view hindered the development of other areas that might have had more promise of ultimate success. (Penrose, 2017: 126).

broaden the interest towards other theories, especially those that can offer something more in the experimental field.

String theory has reached such a point of sophistication that it "just remains" a theory of pure mathematics. Although Penrose has great sympathy for pure mathematics, it is also true that our author hopes that such mathematics can be reflected in the material world, and this is not something that happens with this theory. Now, how right or wrong is Penrose on this issue? Without making an extensive analysis of it (that is, studying sociological, scientific, economic factors, etc.), our author does seem to be right, since, string theory being almost obsolete[11], it still has support with which other theories do not count.

Being fashionable or not, Penrose's position makes contact with many fields of knowledge and the philosophical implications that his proposals give us make his a truly comprehensive perspective. Let's see, in broad strokes, what his twistor theory consists of.

4. How twistor theory fits into physics´ reform

As we saw above, Penrose's proposal belongs to the current of theories that try to find quantum gravity. On a practical level, one of the greatest difficulties that these theories that seek to unify the theory of general relativity and quantum mechanics have to face is that the former has a broad explanatory power with respect to macrophysical processes, while it has no say in microphysical processes; and with the second, just the opposite happens. Can twistor theory get around this problem? Penrose defends that it can and thinks that one of the fundamental pieces for it (if not the most fundamental) are the complex numbers.

It is convenient that before we know some of the characteristics of what allows us to conceive twistor theory as a serious theory to be taken into account as a possible descriptor of reality.

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[11] As we could see in note 10, according to Penrose, string theory continues to be important and valid within the realm of pure mathematics; however, as a physical theory its results are not so satisfactory. Its increasing degree of complexity and abstraction make its applicability to the physical realm less and less clear. On the other hand, there are those who consider this statement by Penrose to be too extreme.

As is usually common in Penrose's approaches (not only at the level of his mathematical reasoning, but of his thinking in general), for our author it is very important that what his defense is based on does so with respect to geometric arguments (Penrose, 1991: 377), (Penrose, 1991: 529). Twistor theory has a very strong geometric basis. Without going into all the details of the geometry that surrounds it, since it belongs to a very advanced geometry that little or nothing would help the subject of this work, we will see some of the features that will allow us to have a clearer idea of the aims from Penrose.

Our author usually begins[12] with the exposition of a light ray, because in it we could find the image of the twistor. Apart from being in the light ray, the twistor characterizes the spin of the particles[13]. Such a light ray is located in a standard spacetime (the 4-dimensional Minkowski spacetime, usually denoted M). The next step is to try to map that light ray to another more fundamental space, which Penrose calls a twistor space (denoted PN). The reason why he makes this correspondence is because in twistor space we can obtain certain structures that in spacetime cannot be contemplated, at least not so easily. To carry out the correspondence, Penrose uses an element that he considers useful for it, that is, the Riemann sphere.

The Riemann sphere represents in the twistor space a point of the light ray in spacetime. The way Penrose uses the Riemann sphere is quite different, as he adds a plane that "cuts" the sphere at the equator. But this is not just any plane, rather it is the Wessel plane[14], which allows us to contemplate and handle the set of complex numbers. As we have seen above, one of Penrose's main motivations for the development of twistor theory is that he is convinced that with it the "magic" of complex numbers can be understood in the best possible way (Penrose, 2004: 978). But this does not mean that twistor theory is due to a simple matter of taste on Penrose's part, since complex numbers are essential to the understanding of quantum mechanics.

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[12] The following exposition belongs to the latest versions of twistor theory. Having first been outlined in the 1960s, the theory has undergone some modifications.

[13] Penrose specifically speaks of photons.

[14] Also known as Argand plane or Gauss plane. Penrose prefers to call it as he does because it was Caspar Wessel, a Danish-Swedish cartographer and mathematician who lived between the 18th and 19th centuries, who first used this map.

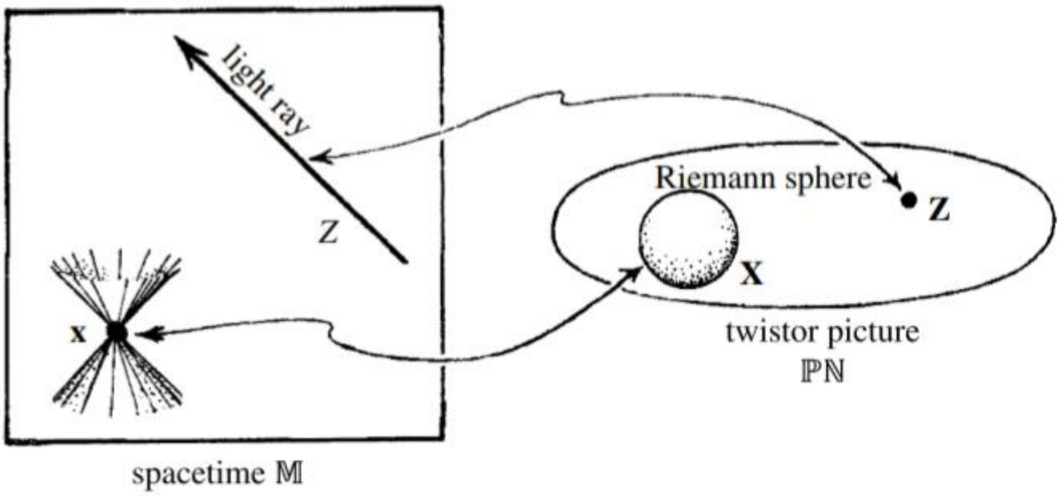

Figure 1. Illustration of the basic correspondence between the Minkowski spacetime M and the twistor space PN, where the light ray in M is seen to correspond to a point in the PN and the point (or event) in M corresponds to the Riemann sphere in PN.

An idea that usually arises from the correspondence with twistor space is that we can get too far from physical reality, due to its pure geometric nature. But despite the fact that there are differences with respect to the structural framework of the reality of spacetime, Penrose asserts that ultimately twistor space does not describe an abstract reality or one that can become strange to us if we want to concretize it:

> […] Although the particular algebraic descriptions of twistor theory differ from the conventional ones, there is nothing unconventional about the interpretations I have just given. At least at this stage, twistor theory provides merely a distinctive formalism. It does not introduce any new assumptions about the nature of the physical world (unlike, for example, string theory). It does, however, give us a different slant on things, suggesting that, perhaps, the notion of space-time might be usefully regarded as a secondary quality of the physical world, the geometry of twistor space being regarded as somehow more fundamental. It must also be remarked that the framework of twistor theory has certainly not, as yet, achieved any such exalted status, and its current utility in scattering theory for very high-energy particles (referred to above) rests entirely on the utility of the twistor formalism for the description of processes for which rest masses can be ignored. (Penrose, 2016: 340-341).

The scheme of twistor space in which the Riemann sphere and the Wessel plane are contained makes it possible to express quantum mechanics, thanks to the implication of the complex numbers in both elements. Besides, the Riemann sphere has a kind of "double function" in the whole scheme proposed by Penrose because it is not only relevant at the level of quantum mechanics, but also at the level of the theory of relativity (this sphere plays an important role spacetime in the theory of relativity, since the field of view of an observer can also be considered as a Riemann sphere). One of the characteristics that Penrose adds to the Riemann sphere is (he speaks in terms of “stereographically projecting”) an infinite point. This idea is a counterintuitive one, but it ends up giving the expected result, that is, obtain the necessary symmetry.

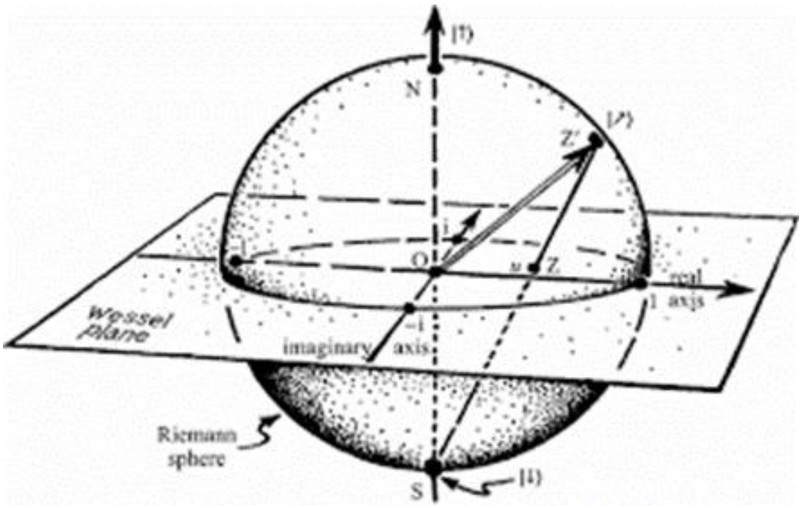

Figure 2. Riemann sphere “cut” by the Wessel plane

Although twistor space PN is presented as a more fundamental space than spacetime, this does not mean that, as explained so far, it is complete. The space PN cannot be considered complex, because it has five real dimensions, and a complex space requires an even number of dimensions. However, there is a way in which we can obtain that complexity, that is, by assigning spin -although it is more precise to speak about helicity- and energy to the particles of light rays. In this way we end up conceiving a 6-dimensional projective space that is denoted PT. This does not mean that the space PN disappears, but rather that it accommodates itself within PT, dividing it into two complex varieties PT^+ and PT^-, where PT^+ can be considered to represent massless particles of positive helicity and PT^- represents massless particles of negative helicity[15]. (Penrose, 2004: 965). This needs to be properly understood. Although the PN space is 5-dimensional and can achieve complex status through the assignment of helicity and energy to light rays, it does not mean that the space it contemplates for reality is 5-dimensional or 6-dimensional. The fact that the Riemann sphere is inside the space PN allows reality to be conceived as 4-dimensional. Moreover, spacetime geometry of twistor theory only makes sense if it is understood within the 4-dimensional scheme, since it does not work for higher dimensional geometries, this being one of the aspects that makes the twistor theory incompatible, for example, with string theory (Penrose, 2004: 967).

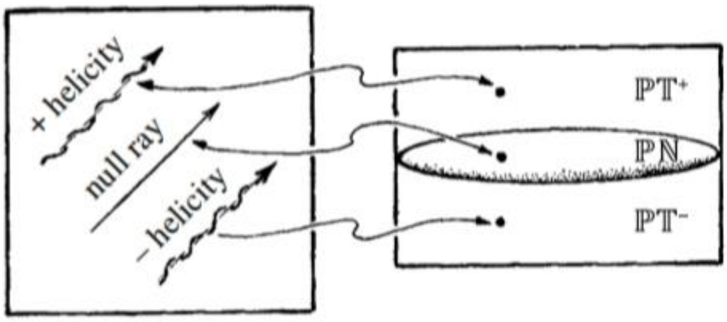

Figure 3. Illustration of the composition of the projective twistorial space PT, where PT^+ represents the right-handed massless particles; PT^- represents the levorotatory; and PN represents those that have no spin.

Continuing with the concepts that it is convenient to take into account when having a more complete idea about how the correspondence between spacetime and twistor space occurs according to the Penrosean theory, we will see another of the fundamental pieces: the conformal group. The conformal group is a mathematical device used in twistor theory to properly understand its geometry and how it can be related to the geometry of physical spacetime. Not being directly related to spacetime, this group is not expressed in Minkowski spacetime M, but

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[15] This can lead us to think twistors as massless particles and this is not correct. Twistors are to be understood as providing the variables in terms of which massless particles are to be expressed (2004: 965-966).

in an extension of it, which is called compactified space and is denoted $M^{\#}$. The way in which this compactified space is reached is by adding an infinite element (light cone at complete infinity), this being, ultimately, the same resource used in the Riemann sphere, since what is achieved with this is greater symmetry (Penrose, 2004: 969).

Another important concept is the spinor. Penrose argues that the idea of the spinor helps to have a clear idea of what a twistor is. But he also admits that it is not the most transparent (Penrose, 2004: 972) and it is due to the fact that it is too technical in geometric terms, which is why, I consider, the most sensible thing is not to enter this type of exposition[16]. On the other hand, it is convenient to comment that if the spinors have that importance is because they allow us to situate ourselves in a Lorentzian 4-space, which is a conformal manifold, and can also be interpreted as a complex manifold. This suits twistor theory because it reaffirms the condition of being explained in 4-dimensional terms, thus moving away from abstract theories that contemplate a higher number of dimensions, which move away, according to Penrose, from physical reality.

Our author wants to continue in the physical world and that is why he does not renounce concepts that are fundamental in quantum mechanics and that serve for the faithful description of natural processes. One of the most important within the scheme of twistor theory is the concept of non-locality. Penrose exposes it through a mathematical concept that is expressed with increasing weight within the physical results, that is, the *first sheaf cohomology*. Again, attempting to define this type of cohomology would be entering a field that would not help much in the exposition of this work and therefore it is convenient to go to the general explanation that Penrose gives directly:

> […] Let me first try to simplify things by shortening the terminology, and referring to an element of 1st cohomology simply as a 1-function. An ordinary function would then be a 0-function, and we can also have higher order things called 2-functions (elements of 2nd cohomology, defined in terms of collections of functions defined on triple overlaps of open sets of a covering) and so on, with 3-

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[16] For an extended exposition of spinors, see Penrose & Rindler (1984), (1986).

> functions, 4-functions, etc. (The type of cohomology I am using here is what is known as Cech cohomology). (Penrose, 2016: 347)[17].

Penrose insists that the best way to conceive of this type of cohomology is to keep in mind the impossible triangle (or tri-bar, or also known as the Penrose triangle), since with it the idea of non-locality is clearly perceived.

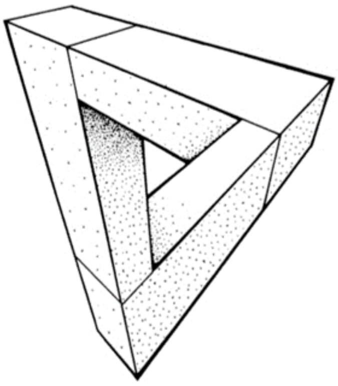

Figure 4. Illustration of the impossible triangle of Penrose, also known as "tri-bar", with which Penrose defends that the first cohomology can be contemplated.

The tri-bar is a structure with three dimensions, but due to its total composition it cannot be expressed in the 3-dimensional Euclidean space, as could be verified if one tried to build it. While locally everything seems to fit together, non-locally it is impossible, since the observer cannot find coherent distances in the structure.

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[17] For an extended exposition of first sheaf cohomology, see Penrose (2004: 987-992), (2016: 347-349).

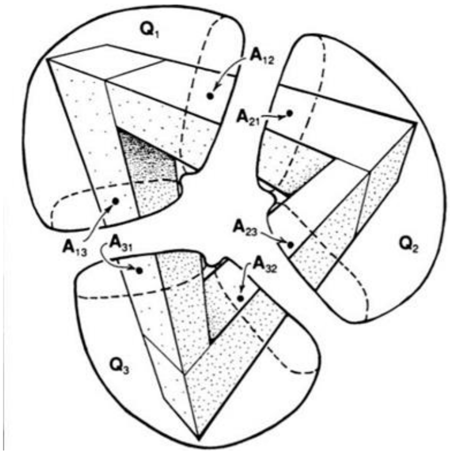

Figure 5. The tri-bar makes perfect sense if we look at it locally, but when trying to build it globally it is impossible.

Regarding the other cohomologies, twistor theory does not have much to say, and this is something that is usually interpreted as showing the limits of the theory. Obviously, Penrose does not agree with this point and thinks, first of all, that twistor theory is not developed enough to conclude that it cannot be related to the other cohomologies in any way; and, secondly, he also understands that it is not so necessary for the theory to go beyond the first sheaf cohomology.

Where twistor theory has found both its possible strength and weakness is in the search for the non-linear graviton. The weakness of the theory is manifest in this section, because with it a physical problem arises that is of considerable difficulty, this is the so-called googly problem (which owes its name to a type of pitch in cricket, specifically the one in which the ball has a right-handed spin, when the throw has been made -apparently- to achieve a left-handed spin). The problem lies in the fact that in this search for the non-linear graviton it is really difficult to find the procedure that explains right-handed gravitational and gauge interactions of this non-linear graviton, which would allow us to find a complete twistorial formulation (Penrose, 2016: 351). The reason this problem is such a setback for twistor theory is because it has been on standby for more than twenty years. However, and here is the part that shows the strength of the twistor theory, very favorable results have recently been obtained about the solution of this problem (in fact, it is to be confirmed in the next few years).

5. The true strength of twistor theory

Penrose is aware that twistor theory today is far from being the ingredient he hopes. As he himself admits, this theory is far from being a mainstream activity (Penrose, 2004: 1003). However, this is not an obstacle for our author to suggest that it is a matter of time before twistor theory continues advancing and shows its capacity.

In what way does twistor theory need improvement to be considered as a serious physical theory? Penrose points out that this would require development in two additional areas in the study of twistor theory, namely, quantum field theory (**QFT**) and twistor particle theory.

Regarding the first, our author points out that some progress has been made, mainly thanks to the contribution of Hodges and his team. Hodges' work is important in that he provides perturbative approaches to **QFT**, introducing what are known as twistorial diagrams (Penrose, 2004: 1001-1002). This is novel and of considerable weight, since these diagrams replace the Feynman diagrams, reaching more satisfactory results. This may seem an advantage that twistor theory has over quantum mechanics, but the truth is that its results are not as extensive as Penrose would like. With the twistorial diagrams it is possible to simplify in some way the results of the Feynman diagrams, but the drawback is that the former cannot ignore the latter, remaining in a kind of state of dependency.

In twistorial theory of particles, the matter seems to be even more complicated. While for massless particles twistor theory has something to say through twistor wavefunctions, as far as massive particles are concerned, its power is limited. The only progress that has been made on this issue was by Zoltan Perjés, George Sparling, Lane Hughston, Paul Tod and Florence Tsou, and it was back in the 1980s, so this problem has not been tackled since then. This, however, is not a problem for Penrose, since he understands that twistor theory could advance in this aspect if it were linked to a proposal that would allow the focus to be changed, this is that of Chan-Tsou (Penrose, 2004: 1002).

Although the future of twistor theory does not seem very promising with what has been seen so far, the fact that Penrose has found a new concept brings hope again to him. This concept consists of another approach to twistor theory and has been introduced by himself. This new way of looking at the theory is called *palatial twistor theory*, and it owes its name to a talk he had with Michael Atiyah at Buckingham Palace. What makes the palatial twistor theory a variant that can continue to give satisfactory answers is precisely because of a characteristic that the twistor theory had at the origin of its development. This feature consists of the basic relationship between twistor geometry and quantum mechanics, specifically the one in which the twistor variables Z and $\bar{\mathbf{Z}}$ are considered canonical conjugates of each other, as well as complex conjugates (Penrose, 2016: 352). The difference of this new version resides in the incorporation of the algebra to the variables in its quantization process, where the variables are replaced by non-commutative operators[18] for the non-linear geometric constructions typical of twistor theory. In what sense can this be important for twistor theory? The procedures that this variable allows can be used when studying certain structures that until now have not been studied from the geometric point of view. Furthermore, it seems that palatial twistor theory allows to provide possible solutions to the googly problem more easily (since it has the ability to describe left-handed and right-handed helicities), as well as the ability to describe curved spacetimes (which would help to deal with the problem of Einstein vacuum equations). Again, this has yet to materialize, although the outlook is optimistic.

Part of that optimism comes from certain advances that have been taking place in recent years. The great authority in theoretical physics, Edward Witten, has contributed to this kind of establishment and development of twistor theory. Witten is known for his contributions to string theory, and this may be surprising, as string theory and twistor theory have come to be seen as incompatible, to the point that advancing one would mean regressing the other (Penrose, 2004: 1004). Witten has not only been able to find aspects that unite both theories, but has managed to make string theory fit the 4-dimensional structure of twistor theory, something that is to the liking of Penrose and his followers.

Finally, it is worth highlighting one of the most recent contributions to twistor theory (2021), again by Roger Penrose, but also largely by Matilde Marcolli. Marcolli and Penrose have

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[18] We have to understand the non-commutativity of these operators in its strict sense, that is, where its variables differ from each other (being like $Z\bar{\mathbf{Z}} \neq \bar{\mathbf{Z}}Z$, in this specific case).

published a joint paper in which the plausible possibility of "gluing" twistor spaces is exposed, which is of special importance with respect to the cohomology involved in twistor theory, but especially with respect to the quantization of twistorial spaces.

Despite the fact that there are important advances in twistor theory, the truth is that these can be found almost entirely at the level of pure mathematics. This is, if we remember correctly, the same problem, according to Penrose, that string theory has to face. In other words, although advances in pure mathematics are strictly necessary, it must also be equally necessary that their applicability should be translatable as clearly as possible to the field of physics. This is probably the biggest problem this theory has to deal with, but the good news is that its evolution points towards a solution to such a problem. The thing is that we can only know that this evolution will success just according to the development of the theory in the coming years, so definitive answer is not possible today.

If anything is clear, it is that twistor theory has to continue to develop if it is to be the necessary ingredient for reform in current physics. It seems that the path that remains is arduous and long, however, the philosophical debates that arise from it are already in force and have come to stay.

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