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INVESTIGATING THE ROLE OF FUNDAMENTAL CONSTANTS IN THE LAWS OF PHYSICS[1]

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ABSTRACT

The fundamental constants of physics have seemingly arbitrary values, that is, we do not know why they have these values. However, important properties of the universe depend directly on these values, since, if they were different, the world would be completely different, and may not even be able to produce the complex molecules that make up living organisms. There is, therefore, a scientific interest in the search for understanding the origin of these constants and even in verifying whether they are in fact constants. The Brans–Dicke theory, formulated in the 1960s, assumes that the gravitational constant G is a field with its own dynamics. Other theories looking at the possibility that fundamental constants are not constant were developed in later years, with varying degrees of success. The present work aimed to carry out a review of these theories, focusing on their essential aspects, seeking an overview of the fundamental constants. In particular, we examine the possibility of a relationship between two important constants, Boltzmann's and Planck's.

Keywords: Fundamental Constants. Boltzmann's constant. Planck's constant.

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INTRODUCTION

A fundamental constant, in principle, is defined as a physical constant independent of the system of units, represented by a number without dimensions. These would be the only strictly universal constants. However, the term can be used to refer to universal physical constants with dimensions, such as the gravitational constant. A constant is always associated with some kind of regularity, so identifying a constant of nature has the meaning of recognizing a pattern of behavior of physical systems. As John Barrow (1994, p.122) says: "And despite the constant flow of changing events, we feel that the world has an invariant foundation, whose general aspect remains the same. Physicists also like to believe that."

Not all constants are equally important. Some are closely related to fundamental laws, such as the gravitational constant, while others only describe characteristics of a physical system, such as the mass of the electron. The constants associated with laws are generally considered more relevant and seen as fundamental. Among them, there are three that are widely considered the most important: the speed of light constant (c), the gravitational constant (G) and Planck's constant (h). However, there is still another aspect that deserves to be mentioned – there are at least three essential physical dimensions: time, length and mass. The combinations of the three constants mentioned above naturally generate a constant for each dimension: Planck time, Planck length, and Planck mass.

Physicists, whenever possible, seek a simplification in their theories, with the reduction of the number of constants that appear in mathematical equations. There are some constants, however, that are dimensionless, preventing them from being eliminated (BARROW, 1994).

The search for clues that prove whether the fundamental constants of physics vary over time or not is currently an important area of study in the academic world.

Two questions can be asked about the constants of nature, the first being about the value they assume. Could these values be different, or is there some kind of law, reason, or reasoning that explains the certain value that a constant can assume? Moreover, in the event that a certain constant assumes a different value, what would be the consequence of this fact? A second question concerns the constants that we assume as such: should they in fact be treated as constants, or can they vary in some way?

With respect to the three most fundamental constants, the possibility that each of them is not a true constant has already been investigated, and the first of them to be examined was the gravitational constant. According to Clifford Will (1996), the Brans-Dicke theory is defined as a theory of gravitation with *variable G* . Recently, João Magueijo (2003) proposed a theory for the variable speed of light and Sabine Hossenfelder (2013) verified the possibility of Planck's constant varying with time. All these theories are speculative and have no direct experimental proof, but remain viable alternatives.

The physicist Alaor Chaves, in his textbook "Basic Physics: Gravitations, Fluids, Waves, Thermodynamics" (CHAVES, 2007), presented the hypothesis that there would be a relationship between two fundamental constants, Planck's and Boltzmann's. One of the objectives of the present study was to verify the validity of this hypothesis.

MATERIALS AND METHODS

The work was developed in two stages. Initially, a literature review was carried out on the theme of several aspects related to the constants of nature.

The theoretical basis was acquired through the following texts: "Theories of Everything: The Search for the Final Explanation", whose author is John Barrow (1994); "Basic Physics: Gravitations, Fluids, Waves, Thermodynamics", by Alaor Chaves (2007); the article "A possibility to solve the problems with quantizing gravity", by Sabine Hossebfelder (2013); "Faster than the Speed of Light", by João Magueijo (2013); "The Big, the Small and the Human Mind", by the author Roger Penrose (1998); "Only Six Numbers: The Deep Forces That Control the Universe", by Martin Rees (2000); and "Was Einstein Right? Putting General Relativity to the Test", whose author is Clifford Will (1996).

In the second stage of the work, he concentrated on carefully examining the hypothesis of Alaor Chaves, whose reasoning involved black-body radiation. Special attention was paid to the Stefan-Boltzmann law.

RESULTS AND DISCUSSION

The present project, as previously listed, aimed to carry out a bibliographic review on themes related to the constants of nature.

In the development of the project, it was possible to achieve a theoretical basis on the fundamental constants of nature, the six numbers that govern the universe and the Brans-Dicke theory, as well as to carry out the analysis of the hypothesis proposed by physicist Alaor Chaves.

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ISSN: 2358-2472

John Barrow, in his book entitled "Theories of Everything: The Search for the Final Explanation", presents an overview of the role of the fundamental constants of nature. He says (1994, p. 122): "To give a quantity the epithet of 'constant of nature' is to attribute to it a privileged condition in the scheme of things."

In the work "Only Six Numbers", the author Martin Rees (2000) states that the universe is modeled by only six numbers, two related to the basic forces, two fixing the size and texture of the universe, and the last two related to the properties of space itself. These six numbers are:

- Ɲ, which measures the intensity of electric forces;
- Ɛ, which defines the strength of the bond between atomic nuclei;
- Ω, which measures the amount of matter in our universe;
- λ, which corresponds to a cosmic "antigravity";
- ϙ, which represents the ratio between two fundamental energies at the time of the Big Bang;
- Ɗ, whose number represents the number of spatial dimensions of the world.

If any of these numbers were changed, the universe would be such that life would not have developed. According to Martin Rees (2000, p. 23), "The laws of physics and geometry could be different in other universes, and this offers a new perspective on the apparently special values that the six numbers have in our universe."

Author Clifford Will (1996) presents a conceptual introduction to the scalar-tensor theory of gravity, known as the Brans-Dicke theory, which was the first theory formulated to investigate the possibility that a fundamental constant of nature is not truly constant. Robert Dicke experimentally considered methods of detecting the variation of the gravitational constant G and raised questions about Einstein's work, asking whether the physicist had made mistakes in his statements about gravity.

João Magueijo (2013), a Portuguese physicist, proposed a theory in which the speed of light is not a true constant, with its value varying slowly over time. His theory presents itself as a competing hypothesis to an aspect of the standard cosmological model accepted today, a phase through which the universe would have passed, known as the *inflation* phase. If Magueijo's theory is correct, inflation would not have occurred.

Physicist Sabine Hossebfelder (2013) examined the possibility that Planck's constant, fundamental in quantum mechanics, is not constant. She proposed that this constant was actually a physical field, which would have had a zero value at the beginning of the universe, but then would have undergone a dynamical evolution, eventually stabilizing at the small non-zero value that we measure today.

Roger Penrose's (1998) text highlights the fundamental role of the three fundamental constants, *c*, *G* and *h*:

- The speed of light (*c*) has a direct relationship with relativistic phenomena, such as the relativity of time and space, which are described by Einstein's theory of special relativity. The value of *c* is very large, but it is finite. If its value were infinite, the world would not be relativistic. This would also affect some properties of the electric and magnetic fields, since light is an electromagnetic wave.
- The gravitational constant (*G*) is related to the phenomenon of gravitation. Its value is relatively small; If it were null, there would be no force of gravitational attraction in the universe.
- Planck's constant (*h*) refers to quantum phenomena, which are important on very small scales, such as that of atoms and elementary particles. Its value is very small; If it were null, there would be no quantum phenomena.

We realized, then, that in the proposal made by Hossenfelder, the universe would start out totally non-quantum and would only start to present the properties that we recognize today as quantum later, when *h* acquired a non-zero value.

The final point of the present work was to investigate, based on the work of Chaves, the possibility of two constants, Boltzmann's (*kB*) and Planck's (*h*), being related to each other.

Boltzmann's constant plays an important role in statistical mechanics. It appears in the statistical definition of entropy:

$$S = k_{\mathrm{B}}\, ln\, W, \tag{1}$$

where *W* represents the number of microstates of a physical system that are macroscopically equivalent.

Chaves presents the following hypothesis:

Revista
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> As we conclude this section, we think we are prepared to give an answer to the original question. Initially, we must admit that any universe that does not violate the laws of logic is in principle possible. Since quantization does not seem to be a requirement of logic, it would be possible for a non-quantum universe to exist. But such a universe would be very strange indeed. In it, there could not be a magnitude like entropy, because its value would be infinite. Or, alternatively, in this universe Boltzmann's constant would also have to be zero. In fact, there is at least one other reason why a finite value for *kB* requires a finite value for *h*. The fact is that if *kB* were finite and *h* were zero, any body would radiate an infinite amount of thermal energy. This fact, known as the ultraviolet catastrophe, was discovered as soon as they tried to understand thermal radiation from statistical mechanics. In fact, Planck postulated a finite value for *h* precisely to evade this catastrophic prediction. At the present stage of science. We still can't say what the origin of the universal constants is. But the discussion just presented seems to indicate that Boltzmann's constant and Planck's constant are closely intertwined, and that understanding one requires understanding the other. (CHAVES, 2007, p. 226).

In essence, Chaves states that if *h* = 0, then *kB* = 0. He cites two reasons why his proposition is valid. The first is that, according to him, with *zero h* , any physical system would have an entropy of infinite value. This is related to equation (1): in a non-quantum world, in which *h* = 0, *W*, which Chaves associates with the number of cells in a given phase space, would be infinite, forcing entropy to be infinite (2007, p. 225). Therefore, to maintain finite entropy with *infinite W* , *kB* would also have to be zero. However, this argument is not entirely convincing, since *W* is the number of microstates equivalent from a macroscopic point of view, which does not necessarily correspond to a count of cells in phase space.

The second argument cited by the author says that, in a non-quantum world, every body would radiate an infinite amount of thermal energy. To prevent this from occurring, we would have to have *kB* = 0. We can analyze this argument through the Stefan-Boltzmann law, according to which the power radiated by a black body is proportional to the fourth power of the absolute temperature of the body. The constant of proportionality is the Stefan–Boltzmann constant, . This constant has the following mathematical expression:σ

$$\sigma = \frac{2\pi^5 k_B^4}{15h^3c^2}. \quad (2)$$

Evidently, Alaor Chaves' reasoning is perceptible: when *h* = 0 with *finite kB* , it becomes infinite. However, the presence of another fundamental constant in this expression is ignored: σc. We can have both *kB* and finite with σh = 0, provided that *c* is infinite (i.e., taking the limit while keeping the product constant). This means that there would be no infinite thermal radiation in a non-quantum world ($h \to 0, h^3c^2h$ = 0), as long as

Revista ARACÊ
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it was also non-relativistic (*c* infinity). Thus, it is possible to admit that Chaves' analysis is incomplete, since it is restricted to only two constants, not taking into account what happens with the others.

CONCLUSION

Based on what was presented in the present work, it is possible to summarize that a literature review study was made on the subject of the main fundamental constants of physics, and that the specific hypothesis of the physicist Alaor Chaves was investigated, regarding the possibility of the existence of a relationship between two important constants, Boltzmann's and Planck's.

Finally, it can be concluded that the analysis performed by Alaor Chaves corresponds to an incomplete study, since restricting the analysis to only two constants, disregarding the other constants involved, is not a totally consistent procedure.

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