In this article we describe and analyze the concept of reality developed by the Austrian theoretical physicist Ludwig Boltzmann. It is our thesis that Boltzmann was fully aware that reality could, and actually was, described by different points of view. In spite of this, Boltzmann did not renounce the idea that reality is real. We also discuss his main motivations to be strongly involved with philosophy of science, as well as further developments made by Boltzmann himself of his main philosophical ideas, namely scientific theories as images of Nature and its consequences. We end the paper with a discussion about the modernity of Boltzmann’s philosophy of science.

1. Introduction

Ludwig Eduard Boltzmann was born on 20 February 1844 in Vienna. In 1863 he started his studies in natural sciences at the University of Vienna and finished his doctorate in physics in 1866, publishing in this same year a paper on the mechanical theory of heat. This choice of topic shows clearly his early interest on the fundamentals of physics, interest which he followed through his entire career. His academic life led him to teaching, research and administrative positions in Vienna, then Graz, Munich, back to Vienna, Leipzig and Vienna yet again in 1902, where he stayed until his death by suicide on 5 September 1906 in Duino, a small city close to Trieste, when on vacation. Boltzmann’s interest in occupying different academic positions were a consequence of his goal of following his most basic ambition: contribute for the scientific progress and institutional consolidation of theoretical physics.

Boltzmann’s contributions to philosophy of science were born out of his intense debates with many other eminent scientists of the time, like

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1 Physics Institute, Universidade Federal do Rio de Janeiro – UFRJ, Rio de Janeiro, Brazil
E-mail: mbr@if.ufrj.br

2 Department of Philosophy, Universidade do Estado do Rio de Janeiro – UERJ, Rio de Janeiro, Brazil
E-mail: guto@cbpf.br
Helmholtz, Hertz, Mach, Ostwald, Duhem, Poincaré, Planck, on the aims and methods of theoretical physics. The intensity and continuity of his participation in these debates shows how important and necessary he considered them for the determination of the nature of theoretical physics. He did not seek to establish a philosophy for physics, even less a philosophy of science in general. His epistemological style was of defending his viewpoints about the fundamentals of science against the criticisms of other scientists and philosophers, who, in his opinion, had mistaken viewpoints about the nature of scientific theories.

Boltzmann’s style of presenting his epistemological viewpoints was also due to one of his most important epistemological principles, which established that in the process of becoming hegemonic among the members of the scientific community, no scientific theory could, for this very reason, exclude other theories. According to Boltzmann, the exclusion of other theories would eliminate the possibility of progress in science since the dogmatic process intrinsic to this behavior would lead to nothing positive. In his view such a process would end up with the impoverishment of the scientific enterprise. Thus, when participating on the debates of his time, Boltzmann was in favor of an open attitude regarding the analysis of various theories. His position in favor of pluralism was reinforced by his belief that, in not a too distant future, science would be deeply transformed in a way that nobody at his time could anticipate with certainty.

Boltzmann viewed the end of the nineteenth century as an epoch of doubts, distrust and growing bad feelings of the scientists towards science. Inasmuch as many were convinced that important changes would forcefully occur, that realization was partially responsible in motivating them to defend their ideas in the hope that one among them could help remove science from the stalemate that it found itself. Such an impasse was due to the inconclusiveness of the debates about the importance of the hypotheses in physics, how a physical theory is built upon, whether or not one must always start from empirical known facts or one could freely use scientific ingenuity and creativity, or still if the physical theories should describe, instead of explaining, the natural phenomena, leaving aside the old ideal of reaching the real causes of them.

When participating in those epistemological discussions, Boltzmann sought first of all to assure the survival of his favorite theories, guaranteeing, at the same time, a place for other theories. The ability of a certain theory to predict...
new phenomena does not make it able to predict its own future and, even less, of science. On the other hand, a theory that had already produced good results should not have been abandoned. Recognizing the scientific limits of a theory does not mean that it should be excluded from the realm of science. Since a theory is incapable of predicting its own future, this conclusion was probably the main reason that motivated Boltzmann in trying to better understand the process along which science develops. His interpretation of Darwinism gave him the basis from where he was able to reach some conclusions, which afterwards opened up the way for him to follow along the path he intended to follow. For Boltzmann a scientific theory is nothing more than a representation of Nature.

2. Basic ideas on reality and scientific truth

According to Boltzmann, the question about the existence of the external world, or matter, must be seen in the light of another problem: “does the answer of this question complicate or simplify our image of the world (weltbild)” [1]. Boltzmann seems to feel necessary to avoid useless discussions, such as those frequently promoted by philosophers. Even though he recognized that there were no definitive proofs either in favor or against the existence of matter, at least at his epoch, he considered that the belief in either position to be ideology. Although he did not define what he meant by ideology, it seems correct to state that for him this word had a negative meaning. In any case, both idealism and realism are, in the end, ideologies. Another important example, certainly of negative connotation and more important than the previous one, about what seems to be Boltzmann’s viewpoint about ideology comes from solipsism. Boltzmann had a true horror of idealism, referring to it as the major madness ever created by the human mind, since idealism denies the existence of the external material world.

From the way he discussed this subject, Boltzmann seems to believe that it is impossible not to choose one of the two positions, namely, idealism or realism. Inasmuch as one cannot in fact prove which position is best, choosing between them can only be made by arguing in favor of an evaluation of the weak points of each position. Then, by evaluating the weak points of idealism, which could not overcome the gap between what is alive and what is not alive, Boltzmann made his choice for the realism. Nevertheless, although he left no doubt about his preference, Boltzmann was careful in the way he referred to these philosophical systems, stating that they are solely manners of
expressions (Ausdruckweise) used for scientists and philosophers to convey their ideas about reality. Realism has a mode of expression more adequate than of idealism. Choosing the most appropriate or most adequate expressing mode would allow the disappearance of false problems. One would not lose so much time in trying to answer false questions, which, according to Boltzmann, is one of the main obstacles to be avoided. The choice of the most adequate expressing mode of science leads us directly to the core of the epistemological thinking of the Austrian physicist.

At the end of the 19th century Boltzmann sought to show that all scientific theories are nothing more than representations, that is, constructions of the natural phenomena. By being representations, scientific theories cannot aim to know Nature itself, knowledge which would explain why the natural phenomena show themselves to us the way we observe them, since such ultimate knowledge is, and will ever be, unknowable. As a consequence, a scientific theory will never be complete or definitively true. This viewpoint actually redefines the concept of scientific truth by advancing the notion that the identification of the theory with the researched objects is a *weak* one, that is, such identification (1) cannot be unique, (2) cannot be complete and (3) is temporarily limited, since scientific theories are nothing more than images of Nature. As a consequence, (1.1) the same aspects of Nature [2] can be represented by more than one theory, which are often in competition among themselves for the preference of the scientific community, (2.1) by being representations scientific theories will never be able to show all aspects of natural phenomena, inasmuch as such a complete knowledge is unknowable, and (3.1) a scientific theory can, and almost surely will, one day, be replaced by another. It is the possibility of the replacement of one theory by another that defines and constitutes the scientific progress.

Boltzmann's ideas about scientific models as representations are clearly stated in the passage below, quoted from the entry “*model*” of the 1902 edition of the *Encyclopedia Britannica*.

> Models in the mathematical, physical and mechanical sciences are of the greatest importance. Long ago philosophy perceived the essence of our process of thought to lie in the fact that we attach to the various real objects around us particular physical attributes – our concepts – and by means of these try to represent the objects to our minds. Such views were formerly regarded by mathematicians and physicists as nothing more than unfertile speculations, but in more recent times they have been brought by
J. C. Maxwell, H. v. Helmholtz, E. Mach, H. Hertz and many others into intimate relation with the whole body of mathematical and physical theory. On this view our thoughts stand to things in the same relation as models to the objects they represent. The essence of the process is the attachment of one concept having a definite content to each thing, but without implying complete similarity between thing and thought; for naturally we can know but little of the resemblance of our thoughts to the things to which we attach them. What resemblance there is, lies principally in the nature of the connexion, the correlation being analogous to that which obtains between thought and language, language and writing. (…) Here, of course, the symbolization of the thing is the important point, though, where feasible, the utmost possible correspondence is sought between the two (…) we are simply extending and continuing the principle by means of which we comprehend objects in thought and represent them in language or writing [3].

Boltzmann also pointed out that the thesis that a scientific theory is a representation was not new. Kant, in the 18\textsuperscript{th} century, and Maxwell, one of the most important influences upon him in the middle of the 19\textsuperscript{th} century, had both defended similar theses. Other contemporary physicists, like Hertz and Helmholtz, shared similar views. By remembering that others like Kant and Maxwell had already expressed similar propositions, Boltzmann wished to make sure that any theory or model would be continuously perfected, without being excluded by any other “tribunal” than the experience.

The most important epistemological conclusion reached by Boltzmann, and which constitutes the core of his philosophical thinking, is usually called theoretical pluralism. This is a consequence of the thesis that all scientific theories are representations of Nature. By being a representation, a scientific theory is, therefore, initially a free creation of the scientist who can formulate it from a purely personal perspective, where metaphysical presuppositions, theoretical options, preferences for a certain type of mathematical language, and even the dismissal of some observational data, can enter into its formulation. That happens in the period when the theory is formulated. However, in order to make this theory eligible to become part of science, it is necessary for it to be confronted by the experience. If it is not approved in this crucial test, the theory must be reformulated, or even put aside. Boltzmann also emphasized that since all scientific theories are, to some extent, free creations of scientists, scientific work is impossible without the use of theoretical concepts, which originates from the fact that it is impossible the
formulation of any scientific theory simply from the mere observation of natural phenomena.

Theoretical pluralism also states that the same natural phenomenon can be explained through different theories. Still according to Boltzmann, this possibility has its origins in the fact that, as seen above, any theory is a representation, a construction, an image of the natural external world, and nothing more than that. From Boltzmann’s point of view one cannot do science in any other way. Either it is a construction, a representation, or the theory is not scientific. In Boltzmann's words:

(...)_Hertz makes physicists properly aware of something philosophers had no doubt long since stated, namely that no theory can be objective, actually coinciding with nature, but rather that each theory is only a mental picture of phenomena, related to them as sign is to designatum.

(...)_From this it follows that it cannot be our task to find an absolutely correct theory but rather a picture that is, as simple as possible and that represents phenomena as accurately as possible. One might even conceive of two quite different theories both equally simple and equally congruent with phenomena, which therefore in spite of their difference are equally correct. The assertion that a given theory is the only correct one can only express our subjective conviction that there could not be another equally simple and fitting image [4].

In summary, theoretical pluralism synthesizes the fact that, since knowledge of Nature itself is impossible, a theory can only be better than another. It is the necessary mechanism which prevents science from running the risk of stagnation. Within this perspective, truth can only be provisional, and is in fact an approximation achieved by different means, that is, by different theoretical images.

An important consequence of Boltzmann's theoretical pluralism is his notion of scientific truth. One of the main features of modern science is that since the beginning of the modern scientific revolution with Galileo, scientists began to define truth as the complete correspondence between models and observations. We may term this relationship as strong correspondence. Nevertheless, since Boltzmann's main thesis states that all scientific theories are representations of natural phenomena, that is, they are not capable of determining what really constitutes Nature, the concept of truth in modern
science should no longer be one which seeks to determine Nature itself. Therefore, within the context of Boltzmann's epistemological thinking, this strong concept of correspondence should be replaced by a weak correspondence which will in turn enable scientists to choose one model among other possible ones, since more than one model, or theory, may well represent the same group of natural phenomena and/or experimental data. At this moment Boltzmann advances another definition of scientific truth: the adequacy. According to him, theory A is more adequate than theory B if the former is capable of explaining more rationally, more intelligibly, a certain set of natural phenomena, than the latter. In his own words,

(...) let me choose as goal of the present talk not just kinetic molecular theory but a largely specialized branch of it. Far from wishing to deny that this contains hypothetical elements, I must declare that branch to be a picture that boldly transcends pure facts of observation, and yet I regard it as not unworthy of discussion at this point; a measure of my confidence in the utility of the hypotheses as soon as they throw new light on certain peculiar features of the observed facts, representing their interrelation with a clarity unattainable by other means. Of course we shall always have to remember that we are dealing with hypotheses capable and needful of constant further development and to be abandoned only when all the relations they represent can be understood even more clearly in some other way.

(...) We must not aspire to derive nature from our concepts, but must adapt the latter to the former. We must not think that everything can be arranged according to our categories or that there is such a thing as a most perfect arrangement: it will only ever be a variable one, merely adapted to current needs [5].

He also noted that since theories are images of Nature, all have some explanatory power and that a good theory is achieved by being carefully crafted by scientists, in a process similar to Darwin's Natural Selection.

Mach himself has ingeniously discussed the fact that no theory is absolutely true, and equally hardly any absolutely false either, but each must gradually be perfected, as organisms must according to Darwin's theory. By being strongly attacked, a theory can gradually shed inappropriate elements while the appropriate residue remains [6].
In summary, Boltzmann in effect identifies scientific truth with adequacy and the latter with the concept of weak correspondence between our scientific theories and Nature. As opposed to the strong correspondence, which identifies completely a theory with Nature, his concept of weak correspondence implies, as stated above, theoretical pluralism, that is, (1) the non uniqueness of any scientific theory – uniqueness implies dogmatism –, (2) the notion of the unavoidable incompleteness of any theory as they are images of Nature – completeness implies dogmatism – and that (3) all scientific theories are temporally limited, i.e., no theory is definitive – all will be replaced one day by better ones.

3. Developments

Boltzmann himself developed further various consequences of the views outlined above. As a convicted Darwinist, he extended the notion of theoretical pluralism to reason itself. For Boltzmann, the brain was a device, an organ aimed at the creation of images of the world which, due to the great usefulness of these images to the conservation of the human species, as determined by Darwin’s theory of Natural Selection, has reached a certain degree of perfection. The brain can be thought of as being a physical structure ruled by evolution. So, reason will necessarily evolve by means of Darwin’s Natural Selection, meaning that Kant’s a priori philosophical category can, and will, change with time.

Another important point to note is that although theories are representations, and, as we saw above, personal theoretical options can enter in their formulation, they are not entirely arbitrary due to the principle of weak correspondence between scientific theories and the external world, principle which is implicit in Boltzmann’s philosophical thinking. The basic aim of any theory is to represent something that is going on in Nature, and a successful theory does achieve this to a considerable extent. Therefore, such a theory can use some symbols, or a specific mathematical language, just as conventions. However, since Nature itself must be represented in it, or, stating the same, Nature must be weakly corresponded in any theory, conventions will always be limited to only those aspects of the model, of the constructed representation, which are not perceived, in that theory, as being directly dictated by Nature. Thus, under Boltzmann's perspective, one cannot say that theories are just conventions, because after being carefully crafted by the scientists as representations of unique, non-arbitrary, natural phenomena, they
become attached to them, and end up saying something about what is really going on in Nature.

In addition, besides being a good representation, there is still another criterion capable of conducting the preference of scientists towards one particular model: its predictive ability. This is important because once a certain theoretical prediction is confirmed, the scientific knowledge about Nature increases quantitatively due to the weak correspondence principle. A correct prediction is also important because it is formulated within the context of a specific theoretical picture. So, by being capable of predicting unknown phenomena, a model shows all its explanatory power since it is not only capable of announcing the already known “pieces”, but it is also able to go even further, showing the existence of other still missing pieces which are necessary for a deeper and more organized understanding of Nature. One cannot forget that one of the most important aims of science is to increase and organize our knowledge about Nature, and thus, a certain theory is richer than others if it is able to better contribute to such an increase and organization. Such a preference for the richer theories makes them more likely to be used and developed than the poorer ones – even by the incorporation of many useful elements of the poorer theories – and after a while the distance between them can be so great that it may no longer be worth for researchers to keep on working with the poorer representations, which are then put aside and, eventually, forgotten.

One must stress that the theoretical pluralism does not necessarily imply competition among the different theories, but often means complementarity. Inasmuch as all theories have some explanatory power, all theories end up saying something about the physical process that are going on in Nature since not all theories use the same set of ideas and phenomena which they seek to explain. Therefore, the emergence of different theories for similar sets of physical phenomena far from being a problem for our better understanding of Nature is an essential ingredient for it. And if those different theories have elements which contradict each other, observations and experimentation provide us the first mechanism, but not the only ones, which allows us to discard the inappropriate elements of the emergent theories.

Under Boltzmann’s view we can clearly see the importance of orthodoxy in science. Inasmuch as the validation of new theories and models usually takes time, a certain degree of conservatism towards new theories and models, and skepticism towards new observations, is, nevertheless, necessary since it is not
possible to build a sound conceptual and experimental scientific body when there is a continual change in the fundamental scientific concepts. Such skepticism is also evidence of the existence of critique in science, which is one of the most important ingredients of modern scientific reasoning and practice. Therefore, orthodoxy plays the healthy role of preserving the scientific knowledge obtained on solid bases until new theories prove to have sufficient internal consistency and experimental validation.

However, when strong conservatism and orthodoxy becomes deep rooted in the scientific community, a situation may arise that, if not effectively and successfully challenged, may lead the community to avoid altogether any kind of change of the established ideas [7]. In such an environment the established theories crystallize, becoming dogmatic and the scientific debate ceases to exist. So, we can conclude that dogmatism works against scientific progress and the adoption of the theoretical pluralism can avoid its dangers, something that Boltzmann’s was very much aware due to his passionate defense of the atomic concept which, at the time, was facing a growing number of powerful opponents, like Ostwald and Georg Helm (1851-1923), who considered the atomic picture of the world outdated and proposed an entirely energetic view of the physical world. Boltzmann feared that such a purely energetic representation would lead physics to become dogmatic, a fact that would inevitably also lead to its stagnation. So, when Boltzmann advanced theoretical pluralism he had the goal of establishing a clear and unreachable limit for dogmatism. Boltzmann believed that once theoretical pluralism were accepted and completely absorbed in the research practice, it would not allow that, once proposed, a theory could be excluded from the scientific scenario.

Another consequence of the theoretical pluralism is that if our scientific theories and models represent Nature by constructions, their descriptions are unavoidably and intrinsically limited. So, if scientific theories are incomplete, there must be knowledge outside science. In other words, there must be other types of knowledge which cannot be classified as scientific, but which nevertheless do reflect, or mirror, processes and phenomena that do occur in Nature. That type of knowledge can be considered unstructured in the sense that it lacks internal connections produced by theoretical thinking. So, that kind of knowledge is affirmative knowledge in the sense that is states that things are as they are because they are found, experimented or observed to be as they are. No further attempts at structuring and searching for internal and external connections are made. If so, and successful, such an affirmative knowledge becomes no longer affirmative and starts to transmute into
phenomenological science. The intrinsic incompleteness of any scientific discipline means that various types of affirmative knowledges will always exist.

Theoretical pluralism also has consequences for the ethics among scientists. By being representations, that is, constructions from, or images of, Nature, the scientific theories are therefore human constructions, reflecting Nature without governing them. So, those images are built by generations of scientists and this line of thought leads us inevitably to suppose that the relationship among the scientists themselves should play a relevant role in this constructive process. The existence of a free flow of ideas is essential for this construction, as well as the permanent critique and stimuli for the existence of motivations for the scientist. All that implies certain behavioral rules, that is, an ethics, required so that the scientific enterprise moves on and avoids stagnation. Although our scientific theories do reflect Nature, they are, and will ever be, human constructions and, therefore, rules obliging the respect and possible acceptance of different ideas become essential.

In summary, Boltzmann’s views about reality mean that one cannot confuse the concepts of “reality” and “real”. The former are the set of mental pictures, or images of Nature created by our brains, whereas the latter is Nature itself, the external world, whose ultimate knowledge is and will ever be unknowable. Nature constitutes what is real and, therefore, is outside our brains. Reality, however, is the collection of mental pictures created in our brains by its interface with what is real, with Nature. Reality, thus, connects our brains with what is real, with the external world, meaning that reality is realistic. This last statement means exactly this connection. Reason then can be thought of as being the “logical rules” [8] that govern reality. But, since reality is made of mental pictures, or images, of Nature, and which will necessarily change with time, we can only conclude that reality and reason must evolve.

4. Modern consequences of Boltzmann’s ideas

A hundred years after Boltzmann’s death we are entitled to ask how modern Boltzmann’s philosophy of science really is. Are his ideas capable of influencing our modern thinking? Could his epistemology be further developed and, if so, what news results and conclusions could it bring about?
Although we cannot know whether or not there will ever be a consensus on the adequate interpretation of the philosophical ideas developed by Boltzmann, it seems to us that it is impossible to deny that he developed his ideas with the intention of using them to counteract the creation of scientific and philosophical dogmas. Boltzmann believed in the importance of his ideas, mainly because they could contribute to the strengthening and improvement of science, philosophy and the human life in general. His ideas could serve as inspiration for the eternal path taken by the human species in its struggle for survival and should not be considered as the last words about such topics. For Boltzmann the authentic progress would only be achieved if human beings could continuously improve themselves. His definition of certainty frames this perspective: “We design as true the actions whose results produce desired things, as well as the representations that direct us to act that way.” [9] In other words, Boltzmann seems to place “action”, “intention”, “representation” and “truth” on the same level of importance. These four concepts would constitute a balanced and indivisible web. The key idea responsible for the maintenance of this balance is exactly his concept that the scientific theories are representations.

One can conclude by stating that our theoretical constructions, or images of Nature, can be applied to physics itself. So, if physics is a construction, as a logical consequence of Boltzmann’s ideas physics must also follow Darwinian Natural Selection as a solution to its philosophical problems. Actually, Darwinism in this sense can be applied to science in general. Therefore, one must not seek explanations beyond human activity and beyond what we can reach with our ordinary senses and our brains.

The activity of constructing images of the external world, as well as the process of improving them so they become more adequate representations, are instinctive to human beings [10] and, therefore, they are not the solely privilege of scientists. Ever since their appearance on this planet, humans have been using their ability to construct internal mental pictures of the external world to control their surrounding environments. In order to survive, humans need to act and intervene on the environment. All representations, including those we call scientific theories, have a practical side which allows mankind to make better use of Nature in their own benefit. Therefore, representing is a human activity as ordinary as any other and there must be a common substratum to any human activity, being not relevant if this activity is intellectual or not. Thus, representing becomes a construction since it requires
practical decisions and choices necessary to solve problems whose solutions we seek. Representing then is nothing more than acting.

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[8] Boltzmann did not believe in “logical rules of reason” in the strict sense, but only as a result of the evolutionary processes incurred in our brains

[9] Boltzmann, L., 1905, “Populäre Schriften,” ed. J. Barth, (Leipzig), p. 164

[10] Boltzmann, L., 1905, “Populäre Schriften,” ed. J. Barth, (Leipzig), p. 179