A Tribute to Max Born in The Fiftieth Anniversary of His Death

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Abstract- In this article we are pleased to present some topics in Physics in order to honor MAX BORN, one of the founders of quantum mechanics, on the occasion of the 50th anniversary of his death. As is emphasized by physicists and historians, Born's technical writings were dense and difficult, requiring beyond knowledge the reader's intelligence. In addition to the description of Max Born's academic career, some of his ideas on theoretical physics in general and quantum mechanics in particular will be exposed, especially in relation to aspects of the interpretation of probabilistic ideas in quantum theory.

Indexed Terms- Born, waves functions, Quantum theory

BREVE BIOGRAFIA DE MAX BORN

As can be seen in the book by BASSALO and CARUSO (1), scientist Max Born, was born in Breslau, Germany, on December 11, 1882 and died in Gottingen, on January 5, 1970. Born were a German physicist and mathematician, which played a fundamental role in the development of quantum mechanics. He also made contributions to solid-state physics and optics and supervised the work of several notable physicists in the 1920s and 1930s. In 1954 he won the Nobel Prize in Physics for his fundamental research in Quantum Mechanics, especially in the statistical interpretation of the wave function. He entered the University of Göttingen in 1904, where he met three renowned mathematicians, Felix Klein, David Hilbert and Hermann Minkowski. He wrote his thesis on the theme "Stability of Elastic in a Plane and Space", with which he received the Prize from the Faculty of Philosophy of that University. In 1905, he began researching special relativity with Minkowski, and later wrote his habilitation thesis on Thomson's atomic model. A random encounter with Fritz Haber in Berlin in 1918 led to a discussion of how an ionic compound is formed when a metal reacts with a halogen atom, which is currently known as the Born-Haber cycle. In 1925, Born and Werner Heisenberg formulated the representation of the matrix mechanics of quantum mechanics. In the following year, he formulated today's standard interpretation of the probability density function for $\psi * \psi$ in Schrödinger's equation, for which he was awarded the Nobel Prize in 1954. Under his guidance, renowned scientists such as Max Delbrück, Siegfried Flügge, Friedrich Hund, Pascual Jordan, Maria Goeppert-Mayer, Lothar Wolfgang Nordheim, Robert Oppenheimer and Victor Weisskopf, received their doctorate at Göttingen. In January 1933, the Nazi Party came to power in Germany, and Born, who was a Jew, was suspended from university activities. He emigrated to Britain, where he worked at St John's College, Cambridge, and wrote a popular science book, The Restless Universe, as well as Atomic Physics, which soon became a standard textbook. In October 1936, he became Professor of Natural Philosophy at the University of Edinburgh. Max Born became a naturalized British citizen on August 31, 1939, the day before World War II broke out in Europe. He remained in Edinburgh until 1952. Returning to Germany, he retired to Bad Pyrmont. He died there in Göttingen, on January 5, 1970.

I. INTRODUCTION

MAX BORN was one of the most important physicists of the 20th century. BORN's scientific and philosophical contributions are numerous, impacting many areas of knowledge. The depth and variety of his works are extraordinary, but the assimilation of his ideas took place slowly throughout the 20th century. In physics, Born participated in the development of almost all areas existing in his time, in addition, he paved the way for the evolution of quantum mechanics, having interpreted the physical meaning of the wave function. He actively participated in the discussions in all the great debates that marked the physics of his time, providing new explanations for different experiences.

BORN remains, even fifty years after its disappearance, a mandatory reference, not only for historians, but also for active scientists. Born's philosophy of Quantum Mechanics departs from any neo-positivist reading, advocating a conception of science, which does not abandon its purpose of objectivity, in the search for safe objective laws. In his works in the philosophical area he defended a reformulated conception of the real, as the possibility of intersubjective acceptance of all theoretical contribution, evaluated through experimental data. We can sustain, at the root of its legacy, a kind of manifestation, which modifies the traditional commitments of the doctrine of being, given that it redefines the reality of objects based on their invariable observations. Born contributed decisively to the characterization of dual wave particle concepts, of great importance for the establishment of the bases of quantum physics. His theories on the constitution of the atom were based on fundamental axioms about the notion of duality between the corpuscular and undulatory aspects of matter. The axiomatic bases of quantum mechanics were thoroughly reformed by Born, in an attempt to establish a representation of the atom that would meet new particularities associated with the microscopic (BLOSSER [2]). The Quantum Matrix Mechanics (MQM) was developed from the works carried out by the German physicists Max Born, Werner Karl Heisenberg and Ernst Pascual Jordan. In effect, on June 13, 1924, Zeitschrift für Physik received for publication a work by Born, entitled Über Quantenmechanik (“About Quantum Mechanics”).

II. THE BORN-EINSTEIN LETTERS

In this paragraph we review the book of HEIMANN [4] entitled: The Born-Einstein Letter, reporting the correspondence between Albert Einstein and Max Born from 1916 to 1955. You know that the two main directions of the modern revolution in 20th century physics are quantum theory and the theory of relativity, the first initiated by Max Planck in 1900 and the second by Albert Einstein in 1905. It is mainly about these two modern theories that the scientific dialogue between Max Born and Albert Einstein takes place in the 120 letters published in The Born-Einstein letters covering the period from 1916 to 1955, when Einstein dies. But many other themes are also present in this correspondence, especially the two world wars that take place in the meantime, observations on politics, social criticism and the personal tragedy experienced by countless scientific figures in the midst of hunger and destruction. The main hallmark of the letters is the difficult combination of deep friendship and incorruptible intellectual honesty. Born and Einstein were lifelong friends and had profoundly different personalities. Both were of Jewish origin, but Born's family had converted to Lutheranism and sought to integrate into German society. Einstein was independent and had no students or research group. Born, by contrast, created a physics school and had more than a dozen doctoral students. While Einstein had separated from his first wife, leaving the children of this marriage unprotected, Born had a stable family and was constantly concerned about his future and well-being. Until 1924, the scientific content of the letters dealt mainly with the theory of relativity. It is the period when Einstein becomes world famous, especially after the experimental confirmation of general relativity. At that moment, attacks against Einstein, who is accused of seeking publicity, and against his theory began to appear. These charges are generally anti-Semitic. After 1924, scientific subjects became almost exclusively about quantum mechanics and this is where the great differences between Born and Einstein are revealed. Born defends the standard interpretation that the results of quantum theory are essentially probabilistic. This thought is commonly called the Copenhagen Interpretation, and attributed to the group of Niels Bohr, however, it was created by Born and won him the Nobel Prize in 1954. Einstein also received the Nobel Prize, much earlier, in 1922, but interestingly not by relativity, but by the corpuscular explanation of the photoelectric effect, a subject related to quantum theory. Despite the success, two important names do not accept Born's probabilistic interpretation: Erwin Schrödinger and Einstein. At first, Einstein's position is radical: the probabilistic interpretation is wrong, "God does not play dice". Gradually, it evolves to accept the probabilistic interpretation as correct, but incomplete, until it reaches a position of greater acceptance, rejecting the quantum states that we currently call Schrödinger's cats. All of Einstein's objections to the probabilistic interpretation are answered by Born, who, despite overestimating Einstein and considering him intellectually superior, does not spare him from criticism. It is evident that it is these criticisms, due to the strength of the arguments, which make Einstein, evolve in his point of view. The difficulties caused by world wars occupy a large part of the cards. Born is forced to flee Germany when he is dismissed from the university by the Nazi persecution in 1933. Einstein, giving lectures around the world, decides not to return and settles in California and then in Princeton, USA, where he lives the rest of his life. The concern to receive refugee scientists is a constant for Born, which can be seen in all the letters from 1933 to 1945. Gradually, Einstein develops a bitter and pessimistic view of politics and especially of the population, which tends to brutality and cowardice. Born notes that Americans can even outdo the Nazis, evoking the bombings of Dresden, Hiroshima and Nagazaki. A special part of the letters concerns the correspondence between Einstein and Born's wife Hedwig. She was a poet, very religious and often discussed related topics. In one of the letters she discusses Einstein's detachment and serenity in the face of death. Even Born gets involved in these transcendental discussions, asking Einstein the following question: "how to combine a mechanical and deterministic universe with the freedom of an ethical individual?" Einstein's more human side, which in general is not given to emotional demonstrations, is revealed in these correspondences

III. PHYSICAL INTERPRETATION OF THE WAVE FUNCTION

This paragraph was written based on the book of JAMMER [5] whose title is The Philosophy of Quantum Mechanics. From this book we will better understand the meaning of the wave function. So far, it looks just like an abstract amount. Since the wave function is a complex quantity, it cannot be measured directly by any physical instrument in such a way there is no immediate physical sense to this function. Therefore, let us make it well established that, in fact, the wave function of a system is nothing more than an abstract mathematical representation of the state of the system. It only has meaning in the context of quantum theory. So, what is this function for? May we use it in any way to describe the physical world? Max Born, in 1926, postulated that the probability density P(x, t) obeys the following relation

$$P(x,t) = |\Psi(x,t)|^2 = \Psi*(x,t)\Psi(x,t) \qquad (1)$$

So that the probability of finding the particle between the positions x and x + dx, at time t is given by

$$P(x,t)dx = |\Psi(x,t)|^2\, dx = \Psi^*(x,t)\Psi(x,t)dx \qquad (2)$$

This result is known as "probabilistic interpretation of the wave function". Moreover, the probability must be normalized, that is, the probability of finding the particle in any region of space at a given instant of time must be equal to 1, that is

$$\int_{-\infty}^{+\infty} 1\ |(x,t)|^2\, dx = 1 \qquad (3)$$

In quantum mechanics we work with expected values (or mean values) of the dynamic quantities. The expected value of a quantity is defined as the average of the possible values, weighted by the respective probabilities of occurrence. In the case of the position, we have

$$\langle x\rangle = \int_{-\infty}^{+\infty} x\ \Psi*(x,)\ (x,)\ dx \qquad (4)$$

Quantum mechanics, as it follows from the principles discussed above, is an inherently probabilistic theory: whereas in classical mechanics the result of each measurement can be predicted with precision, provided the initial state is known, quantum mechanics under the same conditions offers only probabilistic predictions. The nature of these probabilities, on the other hand, differs from those of classical physics: they do not happen due to lack of knowledge, because the wave function contains all the information about the state of a system, and the probability densities present terms of interference because they are the result of the squared module of amplitude sums. In contrast to classical physics, the measuring device modifies the state of the system, which is usually, after conclusion of the measurement, in a different state. What happens to the system during the measurement? How should the measuring device be used to carry out the measurements? These questions, which do not appear in the classical case, constitute what is called the problem of the measure in quantum mechanics. What happens to the system during a measurement cannot be deduced from the previous principles, nor from the Schrödinger equation, which governs the behavior of quantum systems. The Schrödinger equation is a deterministic temporal evolution equation, that is, the final state is determined univocally by the initial state. Moreover, it is a reversible equation, from the final state one can in principle go back to the initial state, not being able to govern or describe an inherently probabilistic measurement process. Before the measurement, we cannot predict in which state the system will be after the measurement. The problems of measurement represent a matter of great complexity and in many of the books currently used were written not considering this problem as a relevant research topic. Finishing this paragraph we want to mention that the interpretation that is accepted today for the wave function ψ (r, t) was the one formulated by BORN, in 1926, in the magazine Zeitschrift für Physik n. 37, who considered it as an amplitude of probability. Esta interpretação surgiu a partir da verificação experimental de que que o número de elétrons difundidos poderia ser calculado por intermédio da expressão quadrática

$$(\left| \psi(r,t)\ \rho \right|)^2 \qquad (5)$$

This formula was built from the amplitude of the secondary spherical wave, which wave is generated by the scattering atom of the incident electronic beam. It is interesting to note that the value of any physical observable (position, speed, energy, etc.) of a particle can be determined by multiplying that value by the amplitude of probability and integrating into the entire space.

IV. PROBABILISTIC INTERPRETATION OF MEASUREMENT RESULTS

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V. FINAL CONSIDERATIONS

In this study, we seek to situate Max Born's contribution to discussions about models in quantum physics from the 20th century onwards. We point out the possibilities and limitations of his theory regarding the problem of the relationship between knowledge and reality. We also highlight some approaches and departures from his work in relation to other proposals. Due to the limitations of the length of an article, we have not had the opportunity here to detail more specific conceptions of how to implement such contributions in teaching. However, the present study is not the only one in defense of the Bornean framework as potentially fruitful to teaching, so that such propositions have been developed. At the moment, we suggest that Born's ideas are important for analyzing aspects of the conceptualization of teachers and especially with master students in Physics Teaching. As Born himself teaches, it is always possible to approach a problem from different theoretical starting points, without this implying an inconsistency or mutual exclusion. Furthermore, the relationship between theory and physical reality, focused on in this work, is not the only role that models play.

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