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100 YEARS OF QUANTUM MECHANICS: THE MONTHS THAT CHANGED PHYSICS

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ABSTRACT. A hundred years ago, physics underwent one of its most dramatic transformations – a paradigm shift that fundamentally changed our understanding of nature. Over the course of several revolutionary months in 1925 and early 1926, quantum mechanics emerged as a new, foundational theory of the microscopic world. With the publication of key papers by Werner Heisenberg and Erwin Schrödinger, the theoretical framework was established that radically redefined our perception of physical reality. These works demonstrated that atoms and subatomic particles do not obey the laws of classical mechanics, but instead follow entirely new, quantum laws. Born in those intense months, quantum mechanics became one of the cornerstones of modern physics and a lasting source of inspiration in both theoretical and applied sciences. This paradigmatic shift opened new avenues of research and laid the groundwork for scientific discoveries that continue to shape our understanding of nature today. This paper is dedicated to those pivotal historical moments – the months in which science made one of its deepest leaps and most consequential strides in comprehending the world.

Keywords: Quantum mechanics, scientific revolution, Werner Heisenberg, Erwin Schrödinger, old quantum theory, matrix mechanics, wave mechanics.

INTRODUCTION

There are certain periods in human history marked by a sudden and intense flourishing of thought, ideas, and discoveries – epochs in which science advances by leaps rather than steps. One such period was the 1920s, and in particular the months of 1925 and early 1926, which can rightfully be called the "The Beautiful Era" of theoretical physics. It was precisely at that time that one of the greatest turning points in the history of science occurred – the birth of quantum mechanics, a new theoretical paradigm that fundamentally transformed our understanding of the microworld (WEINBERG, 2013; PANTIĆ, 2024; DUGIĆ and JEKNIĆ-DUGIĆ, 2025).

This discipline, which initially emerged as an attempt to explain anomalies within classical physics, soon evolved into one of the pillars of modern science. With the publication

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of key papers by Werner Heisenberg (1925) and Erwin Schrödinger (1926), physics entered a new era in which atoms and subatomic particles were no longer subject to the laws of classical mechanics, but required an entirely new, quantum description. During those intense months, new discoveries began to unveil deeper layers of reality, previously hidden behind the limitations of classical intuition.

The development of quantum mechanics involved the greatest minds of the time: Niels Bohr and his collaborators from Copenhagen, Max Born, Pascual Jordan, Werner Heisenberg, Erwin Schrödinger, Wolfgang Pauli, Paul Dirac, and others. Even Albert Einstein, though later skeptical of some implications of quantum theory, played a significant role in its early stages. Quantum mechanics did not emerge all at once, but rather as a response to theoretical challenges and experimental puzzles, such as the inadequacy of the classical model of electron orbits in atoms.

The United Nations has declared 2025 the International Year of Quantum Science and Technology, precisely in honor of that astonishing scientific leap that occurred a century ago. The aim of this paper is to shed light on those key and turbulent months during which science took a profound turn toward a new understanding of nature, and to show how the ideas born in that short but fruitful period forever changed the course of physics and laid the foundations of modern science and technology.

THE INTENSE MONTHS OF 1925 AND 1926: HISTORICAL MOMENTS IN THE BIRTH OF QUANTUM MECHANICS

A hundred years ago, in July 1925, twenty-three-year-old German physicist Werner Heisenberg submitted a paper to the journal *Zeitschrift für Physik* (HEISENBERG, 1925), which would mark the beginning of modern quantum mechanics and ignite a revolution in our understanding of the fundamental laws of physics – a revolution whose impact is still deeply felt today. This pioneering work not only represented a turning point, but also stimulated intense research in the months that followed, both through Heisenberg's collaboration with Max Born and Pascual Jordan, and through the work of Erwin Schrödinger, who developed a completely different, yet mathematically equivalent, approach.

Heisenberg's paper represented a bold and innovative effort to overcome the limitations of existing models in explaining atomic spectra – the frequencies and intensities of light that atoms emit and absorb. At the heart of the problem was the Bohr-Sommerfeld model of the atom, developed during the 1910s. This model formed the basis of the old quantum theory, which had emerged as an attempt to interpret certain quantum effects within the framework of classical mechanics. However, it became clear that classical physics was insufficient to provide a consistent explanation of phenomena in the microscopic world, opening the door for the emergence of an entirely new theory.

However, the gap in understanding atomic structure could only be bridged by introducing the ad hoc assumption that energy does not flow continuously, but arrives in discrete packets – quanta. The Bohr-Sommerfeld model, as an extension of Bohr's earlier atomic model, assumed that electrons move in elliptical orbits around the nucleus, with their motion governed by specific quantum conditions. This model successfully explained the spectrum of the hydrogen atom, as well as the splitting of spectral lines in the presence of external electric fields (the Stark effect) and magnetic fields (the Zeeman effect). Nevertheless, despite these successes, the model encountered serious difficulties in explaining more complex systems, such as the hydrogen molecule and atoms with multiple electrons.

Heisenberg recognized this problem in 1923, when, as a young scientist, he joined the Institute for Theoretical Physics at the University of Göttingen, where he worked as an

assistant to Max Born. Together, they carried out a series of detailed calculations of the helium atom's spectrum, using all the orbits predicted by the Bohr-Sommerfeld model. However, their results did not align with experimental data. At first, they suspected inaccuracies in the computational methods, but it soon became clear that the issue was a much deeper conceptual one. “It is becoming increasingly likely,” wrote Born (BORN, 1926), “that it will not be enough to simply introduce new assumptions in the form of physical hypotheses, but that the entire system of physical concepts will have to be rebuilt from the ground up.” In a letter to his former teacher Arnold Sommerfeld from December 1923, Heisenberg wrote: “Classical representations of orbits cannot accurately describe the energies and frequencies that appear in real atoms.”

Heisenberg and Wolfgang Pauli both questioned the viability of the orbital model. As early as 1924, Pauli wrote to Sommerfeld expressing that the language used to describe the quantum world was inadequate. Nevertheless, up until April 1925, it remained unclear how to proceed with the development of the theory without relying on classical orbital models.

Sometime later, seeking relief from hay fever on the island of Helgoland, Heisenberg laid the foundation for a more radical approach. Instead of relying on models with clearly defined orbits, he developed the concept of “quantum mechanics”, where electrons were no longer viewed as particles moving along continuous paths. In early July 1925, he wrote to Pauli that all his efforts were directed at completely eliminating the concept of orbits, which, as he pointed out, could not even be directly observed. This marked a crucial break with classical mechanics (MLAĐENOVIĆ, 2008).

In his paper (HEISENBERG, 1925), Heisenberg aimed to establish a theoretical foundation for quantum mechanics that relied exclusively on relations between quantities that are, in principle, measurable. He proposed a new approach based on the use of matrices, moving away from the classical notion of particles and waves. Instead of considering traditional concepts such as electron orbits, Heisenberg focused on describing kinematic and mechanical quantities, such as position and momentum, which were represented using matrices in this approach. His equation involved complex matrix sequences that described observable quantities, such as energies and transition amplitudes, which represent the probability of atoms transitioning from one quantum state to another. This work was not only a theoretical step forward but also laid the foundation for the development of matrix mechanics, one of the core formulations of quantum mechanics.

However, it was difficult to understand how the elimination of unobservable quantities could guide the further development of the theory. It was also unclear which quantities should be considered unobservable. As Born later reflected, although the idea of eliminating unobservable quantities seemed reasonable in 1925, in practice such a “general and vague formulation was completely useless, even wrong”. This challenge highlighted the pragmatic approach of Heisenberg’s physics, which often relied on testing various ideas until the one that actually worked in practice was found.

The development of quantum mechanics through the work of Werner Heisenberg marks a break with the classical concept of orbits and introduces a new approach based on matrices. Heisenberg considered unobservable quantities and their role in the quantum description of nature, but it became clear that a more precise approach was needed. The development of matrix mechanics, although initially uncertain in direction, continued to form through experimental and theoretical efforts, laying the foundation for quantum mechanics as a theoretical framework. In the following, Heisenberg’s matrix quantum mechanics, which represented a key step in defining modern quantum theory, will be discussed in more detail.

HEISENBERG'S MATRIX MECHANICS

The physical ideas that led to the emergence of quantum mechanics were first systematically formulated by Werner Heisenberg. Born in 1901 in Würzburg (Bavaria), Heisenberg studied in Munich under the guidance of the renowned professor Arnold Sommerfeld and defended his doctoral dissertation on hydrodynamics in 1923. However, a decisive moment in his scientific development was his encounter with Niels Bohr, the creator of the old (classical) quantum theory, in 1922. Bohr had been invited to give a seminar in Göttingen, which Heisenberg attended. The sharp and insightful remarks of the young student impressed Bohr, who invited Heisenberg to visit the Institute in Copenhagen the following spring, in 1923. This meeting laid the foundation for a long and fruitful collaboration that greatly shaped the development of quantum mechanics (DUGIĆ and JEKNIĆ-DUGIĆ, 2025; MLAĐENOVIĆ, 2008).

The warm, friendly atmosphere at the Institute and in the Bohr household, as well as Niels Bohr's own character, left a deep impression on Heisenberg. Bohr's intuitive approach to studying physical phenomena was an ideal complement to Heisenberg's more abstract method of reasoning. Bohr's method, which did not begin with mathematical formalization but with a deep understanding of the phenomena themselves, had a profound influence on Heisenberg's ability to reconsider and transform his earlier concepts. As Heisenberg himself wrote in an article dedicated to Bohr: "For Bohr, understanding the relationships between physical quantities did not arise from mathematical analysis of theoretical assumptions, but from an intense study of the phenomena themselves, which allowed him to grasp these relationships intuitively, rather than derive them formally."

This collaboration in Copenhagen not only enriched Heisenberg's understanding of quantum mechanics, but also significantly influenced the very structure of quantum theory itself. Heisenberg's work, combined with Bohr's intuition, was crucial for the development of matrix mechanics, which would later become one of the two main pillars of quantum mechanics, alongside wave mechanics developed by Erwin Schrödinger.

Upon being appointed as an assistant at the University of Göttingen, Heisenberg joined ongoing research in the field of quantum theory in collaboration with Max Born and Pascual Jordan. From 1924 to 1927, Heisenberg frequently stayed in Copenhagen, where he continued a fruitful and intense collaboration with Niels Bohr, one of the pioneers of the old quantum theory. At that time, classical quantum theory was at its peak.

Quantum theory originates from Planck's hypothesis, formulated in 1900 by Max Planck to explain the blackbody radiation law. According to this hypothesis, the exchange of energy between matter and radiation does not occur continuously, but rather in discrete, indivisible units – quanta of energy. In 1913, Niels Bohr introduced the concept of quantum jumps between discrete energy levels in his atomic model, providing a mechanism for explaining Planck's hypothesis. According to Bohr's model, when an electron transitions from a higher energy level E_m to a lower one E_n, a quantum of light – a photon – is emitted or absorbed with energy $h\nu = E_m - E_n$, where $h = 6{,}626 \cdot 10^{-34}$Js is Planck's constant, representing the elementary quantum of action.

Although quantum jumps and Planck's hypothesis successfully explained a range of experimental data, Bohr himself believed that the concept of the quantum of light served only a supplementary mathematical role and did not accept the physical reality of the photon. His position was that Einstein's corpuscular theory of light – proposed in 1905 to explain the photoelectric effect – could not be reconciled with Maxwell's classical theory of electromagnetism. However, this skepticism was shaken in 1922 when Arthur Compton discovered the scattering of X-rays by electrons – a phenomenon that could only be explained

by attributing a particle-like nature to radiation. This led to the acceptance of the idea that radiation simultaneously possesses both wave and particle properties – a phenomenon that would later become known as the wave-particle duality of light. This profound conceptual dilemma remained beyond the reach of classical quantum theory.

Faced with this challenge, Bohr spent years trying to find a way to unify the wave and particle nature of light into a single coherent theory. However, by 1924 it had become clear that the classical quantum model was insufficient to explain more complex atomic systems. While Bohr's theory successfully described the hydrogen atom – the simplest atomic model – it could not account for the fine structure of the spectrum or other experimental results. Theoretical physics found itself in a crisis that demanded a radically new approach. It was at this historical moment that Heisenberg emerged with his new perspective based on matrix mechanics – a revolutionary method that would mark the beginning of modern quantum mechanics.

In the spring of 1925, Werner Heisenberg attempted to calculate the intensities of lines in the hydrogen spectrum using the existing quantum theory. However, he was unsuccessful in this endeavor. He concluded that the difficulties were of a fundamental nature and had to be resolved before any further progress could be made. The idea for how to overcome this problem came from a thought expressed by A. Einstein in his special theory of relativity: that any physical theory must rely solely on observable quantities. Heisenberg realized that the main shortcoming of Bohr's quantum theory was its reliance on quantities inaccessible to experimental observation – such as electron orbits or trajectories within the atom.

Starting from this idea, Heisenberg focused exclusively on experimentally accessible (observable) quantities, such as the frequencies and intensities of spectral lines in atomic spectra. He constructed frequency schemes corresponding to transitions between two stationary states: $\nu_{nm} = (E_m - E_n)/h$ where $\nu_{nm} \neq 0$. Similar schemes could also be constructed for the intensities of spectral lines, as well as for other quantities associated with transitions between stationary states. To each physical quantity, Heisenberg assigned such a scheme.

On the other hand, Heisenberg introduced the assumption that the elements a_{nm} of the scheme for any physical quantity A, associated with the atom, vary harmonically with time in accordance with the corresponding frequency: $a_{nk}(t) \sim e^{2\pi i\, \nu_{nk} t}$. From this law of time dependence follows the multiplication rule for the schemes:

$$a_{nk} a_{km} = e^{2\pi i\, (\nu_{nk} + \nu_{km}) t} = e^{2\pi i\, \nu_{nm} t} = a_{nm}.$$

This law of time variation, as well as the multiplication rule for the schemes, was derived by Heisenberg based on experimental facts. It was known that if two frequencies appear in a spectrum, then their sum and difference also appear in the same spectrum. This empirical rule, known as the Ritz combination principle, receives a clear explanation in the light of quantum jumps – each transition between energy levels generates a specific frequency, and combinations of these transitions result in new spectral lines.

He believed that "a more intensive mathematical investigation" would show whether his method from July was "satisfactory." In Göttingen, this line of research was continued by Max Born and Pascual Jordan, who recognized that the quantities in Heisenberg's equations could be represented as matrices – a new, revolutionary mathematical approach. Together, they reconstructed the theory in terms of matrix mechanics and presented their results in an extensive paper BORN, *et al*. (1926), known as the *Dreimännerarbeit* ("three-man paper"), which they submitted in November 1925. With this work, which preceded paper BORN and JORDAN, (1925), the mathematical foundation of the new theory – **matrix quantum mechanics** – was established.

In the further development and general mathematical elaboration of the formalism of quantum mechanics, significant contributions were made by Paul Dirac and John von Neumann. However, even Heisenberg's initial formulation reveals a fundamental difference between classical physics and quantum mechanics. While classical physics associates physical quantities with ordinary numbers, quantum mechanics assigns matrices to these quantities, whose rules of calculation may differ. For instance, for two matrices A and B, the product AB is not always equal to the product BA. In such cases, the matrices are said to be non-commutative.

What is particularly important is that the coordinate matrix (denoted as X) and the momentum matrix (denoted as P) do not commute, which is mathematically expressed as $XP \neq PX$. This non-commutativity is not merely a mathematical peculiarity but has a profound physical significance – it lies at the heart of Heisenberg's uncertainty principle. This principle establishes fundamental limits on the simultaneous knowledge of a particle's position and momentum in the same quantum state.

Heisenberg attributed great importance to these seemingly purely mathematical aspects of the theory. He believed that the physical meaning of the theory was embedded in its fundamental postulates and that the consistent application of the mathematical framework could yield correct interpretations of physical phenomena – without the need for visual representations or classical intuition. This approach not only eliminated the classical notion of particles as objects moving along well-defined trajectories, but also led to the development of quantum mechanics as a theory based on probabilities rather than deterministic predictions. This radical departure from classical mechanics laid the foundations of modern quantum physics, where the mathematical framework – rather than physically realistic models – plays a central role in understanding the microscopic world.

However, Heisenberg's model came at a cost. As the authors explained, the new theory was not suitable for a geometric interpretation, as the motion of electrons could not be described in terms of familiar concepts of space and time[2]. While Born and Jordan enjoyed the abstraction, Heisenberg, in a letter to Pauli in June 1925, expressed doubt, questioning what the equations of motion[3] he used in his work actually meant. Pauli's successful calculations of the hydrogen atom's spectrum (PAULI, 1926) in December of that year were considered confirmation of the validity of the approach. However, most physicists found it difficult to accept this complex mathematics, so it was a relief when, just a few months later, in 1926, a completely different approach emerged. This approach, which would become known as wave mechanics, represented a new way of considering quantum phenomena and opened the path for further development of quantum theory. We now turn to the discussion of this important breakthrough that would lead to a deeper understanding of quantum systems, where the concept of waves and wave functions would play a central role.

SCHRÖDINGER'S WAVE MECHANICS

Less than a year after the development of matrix mechanics, another version of quantum theory emerged – **wave mechanics**. This new approach was formulated by Erwin Schrödinger, then a professor at the University of Zurich, in a series of revolutionary papers published in the journal *Annalen der Physik* (SCHRODINGER, 1926; SCHRODINGER, 1928). Unlike Heisenberg, who dismissed visual representations in favor of abstract algebraic

[2]This in classical mechanics implies defined positions (coordinates) and trajectories of particles.

[3]In the context of quantum mechanics, the equation of motion refers to the mathematical relation that describes how a quantum system changes or evolves over time.

structures, Schrödinger started from the idea that the fundamental equation of quantum theory should describe the propagation of matter waves.

By 1923, there was sufficient evidence that light possessed a dual nature – both wave-like and particle-like. However, there was no experimental proof that particles on the atomic scale exhibited a similar dualistic character. The first to seriously suggest this possibility was Louis de Broglie. He hypothesized that if Planck's constant relates energy and momentum to frequency and wavelength for photons, then the same relationship should also apply to material particles. De Broglie concluded that the wavelength of a particle is given by the expression $h = \lambda/p$, and the frequency by $\nu = E/h$, where h is Planck's constant, p is the momentum, and E is the energy of the particle. With this bold hypothesis, de Broglie introduced the idea of wave-particle duality not only for light but for matter as a whole.

At the time when de Broglie presented his ideas, the main weakness – aside from the lack of experimental confirmation – was that his formulation did not constitute a complete theory. Classical mechanics could no longer explain all experimental findings, and the quantum conditions that were being introduced *ad hoc* were becoming increasingly numerous and disconnected. The need for a new, unified theoretical framework was becoming more and more apparent.

While Heisenberg, as previously described, was the first to offer a successful solution by formulating matrix mechanics in 1925, only a few months later, Schrödinger developed his own approach based on ideas closely related to de Broglie's hypothesis. In this way, quantum mechanics was born a second time – this time in the form of wave mechanics.

Schrödinger believed that the rejection of visual and spatial representations of atomic processes – as done by matrix mechanics – was a step backward and a loss of hope in understanding the atomic world. In contrast, he was convinced that it was possible to formulate a theory that would describe the dynamics of atomic systems using waves. He formulated a wave equation that successfully described the energy states of the hydrogen atom, thereby confirming the validity of his approach.

Within this framework, the quantum state of a system is described by a complex function of real variables – the wave function, which is a solution to Schrödinger's equation. Although this function itself has no direct physical interpretation, it allows for the calculation of all physically relevant quantities. In this way, the wave function becomes the carrier of information about the state of a quantum system and a central concept in Schrödinger's formulation of quantum mechanics.

Heisenberg, however, did not accept Schrödinger's theory uncritically. After attending a colloquium in Munich where Schrödinger presented his version of quantum mechanics, Heisenberg expressed numerous criticisms in a letter to Wolfgang Pauli. He believed that the wave theory could not explain key quantum phenomena such as the photoelectric effect and the Stern-Gerlach experiment. He also pointed out the difficulties in describing multi-particle systems, which would require the use of a wave function in an abstract, high-dimensional space. Although he acknowledged the usefulness of Schrödinger's formulation as a computational tool, Heisenberg remained skeptical about the physical meaning of the wave function. In a letter from 1926, he wrote: "Even if a consistent wave theory in three-dimensional space were to be developed, it would hardly be capable of providing an exhaustive description of atomic processes within the framework of our known concepts of space and time" (HEISENBERG, 1926; MLAĐENOVIĆ, 2008).

During the following year, Schrödinger persistently tried to find a satisfactory physical interpretation of his theory, but without full success. Although wave mechanics quickly became an extremely useful mathematical framework for solving concrete quantum problems, it did not provide an intuitive description of individual processes within the atom in terms of

traditional concepts of space and time. Schrödinger was deeply disappointed by the fact that the new physical paradigms no longer allowed for the visualization of atomic processes in a manner similar to classical mechanics. This marked a deeper epistemological shift: the atomic world is no less real, but it requires abandoning intuitive images in favor of abstract mathematical symbols. While this allows the physicist to understand and predict phenomena, it significantly complicates the popularization of quantum theory outside professional circles.

Although it did not provide an intuitive explanation of quantum phenomena in the classical sense, wave mechanics nonetheless played a crucial role in the construction of the new theory. In combination with matrix mechanics, it laid the foundation of modern quantum physics and enabled the formulation of a unified theory – quantum mechanics. Concepts such as the wave function and its probabilistic interpretation became central elements of the theory, allowing for a deeper understanding of atomic and subatomic processes. The shift toward this new, more abstract and mathematically grounded view of quantum phenomena marked a turning point in the development of modern physics.

Nevertheless, we should not conclude without addressing some of the problems inherent in quantum mechanics itself. Despite its remarkable successes, the theory also has its weaknesses. One of them is the lack of integration with the general theory of relativity – the universal theory of gravitation. Another challenge lies in the fact that quantum mechanics is still not entirely self-sufficient: for its formulation and experimental verification, it continues to rely on classical mechanics.

The greatest challenge of modern physics may lie precisely in the ability to reexamine – and, if necessary, abandon – fundamental principles when they are shown to no longer hold in new contexts. The history of physics demonstrates that progress has often depended on the willingness to move beyond old paradigms. Although it currently seems unlikely that the ideas of quantum mechanics will be entirely abandoned in the near future, the possibility remains open that future theories will provide even deeper and more comprehensive descriptions of physical reality.

EQUIVALENCE OF MATRIX AND WAVE MECHANICS

As we mentioned earlier, immediately after presenting their theories, misunderstandings arose between Heisenberg and Schrödinger due to differing starting positions and interpretations. From today's perspective, the speed with which quantum mechanics was shaped is remarkable. However, very quickly, at the initiative of Niels Bohr, there was a reconciliation of opinions. In the end, it turned out that matrix and wave mechanics are equivalent theories, representing two different, but mathematically comparable formulations of quantum mechanics.

The equivalence of matrix and wave mechanics was established in the spring of 1926 (SCHRODINGER, 1928), which was a crucial step in the further development of quantum theory. June 1926 was also significant due to the first paper submitted by Max Born, which related to collision phenomena. In this paper, he interpreted the square of the amplitude of the wave function from Schrödinger's theory as the probability that a particle would scatter in a certain direction after colliding with an atom. Soon after, works by Pascual Jordan and Paul Dirac followed, in which they developed the "transformation theory", describing quantum states (and not just transitions between them) in terms of probability amplitudes. This concept laid the foundation for probability as one of the fundamental ideas in quantum mechanics.

A significant turning point in the development of the theory occurred in 1927, when Heisenberg, in one of his papers HEISENBERG (1927), introduced the concept of uncertainty

relations. According to this concept, the more precisely the position of an electron is determined, the less precisely its momentum can be determined (and vice versa). This paper not only completed the development of quantum mechanics but also pointed out the existence of fundamental limitations in the knowledge of two physical quantities, such as position and momentum, which quantum nature imposes, independently of the measurement process.

From mid-1926, physicists began applying quantum theory to more and more practical problems. The development of the theory was so rapid that it was difficult to keep up with all the new methods and techniques. After some physicists mastered the new method, they often found that someone else had already published the same solution earlier. This accelerated pace of development led to frequent complaints about "intellectual overload". The consideration of the deeper meanings and philosophical consequences of the new theories was a privilege of only a small number of researchers who were able to devote themselves to such detailed deliberations.

By the time of the Solvay Conference in 1927, most physicists believed that quantum mechanics had reached its final form. Heisenberg and Born, in their report, declared quantum mechanics a "complete theory", whose basic assumptions no longer needed to be changed. However, not everyone was so convinced. Scientists such as Einstein, Schrödinger, and de Broglie considered the theory deeply problematic.

"Perhaps quantum mechanics is the correct theory of statistical laws", Einstein wrote, "but it does not sufficiently explain individual elementary processes". Einstein remained a critic of quantum mechanics throughout his life, believing that there was a deeper level of reality yet to be discovered. He argued that while quantum theory was successful in mathematically describing phenomena, it did not provide a satisfactory explanation of the fundamental laws of nature and, as such, could not be considered complete. His criticism was particularly directed at the "Copenhagen interpretation", which suggested that we cannot have a complete picture of reality at the subatomic level.

Although some of the most prominent scientists were skeptical about accepting quantum mechanics as the final theory, most physicists nevertheless accepted its accuracy and used it as a foundation for explaining various phenomena. After 1925, quantum mechanics became the basis for significant advancements in physics and chemistry. For example, it explained chemical bonds between atoms, investigated the mechanism of radioactive alpha decay, and clarified the process of electrical conductivity in metals. These results were crucial for the development of new areas of science and technology, particularly in materials science and molecular biology. Theories and discoveries derived from quantum mechanics laid the foundation for numerous innovations, including the development of lasers, semiconductors, and modern computing technologies (DUGIĆ, 2009).

Although quantum theory is still the subject of deep philosophical debates and is not without controversy, it provides an extraordinarily accurate description of all experiments conducted to date. Quantum mechanics perfectly explains phenomena in the subatomic world and serves as the foundation upon which new discoveries and theories are built. Its success in explaining complex natural phenomena, as well as its unparalleled advantage in practical applications, make it one of the most successful and productive theories in the history of science.

Although there are still some open questions, such as the deeper nature of quantum mechanics and the possibility of its integration with the theory of gravity, quantum mechanics remains a key pillar of our understanding of the physical world. Its ability to accurately describe phenomena in the subatomic world, without precedent, remains one of the most significant contributions to science. Deeper questions regarding the physical interpretation of quantum theory continue to spark debates among philosophers and theoretical physicists, but

regardless of the philosophical puzzles the theory presents, which will likely continue to be raised, it has provided extraordinary insight into the nature of our reality. Quantum mechanics, although still surrounded by open questions, remains one of the most successful and fruitful theories in the history of science, opening new horizons for future discoveries and understanding of the universe.

CONCLUSION

The emergence of quantum mechanics a hundred years ago represents one of the deepest and most significant revolutions in the history of physics, fundamentally altering our understanding of nature and the way we interpret physical reality. From the early works in quantum theory to the present day, quantum mechanics has not only provided exceptionally precise mathematical models for describing the world at the subatomic level but has also laid the foundation for the development of technologies that have become indispensable in modern society.

From lasers and semiconductors to supercomputers and nanotechnology, the application of quantum mechanics has shaped the technological and scientific progress of the 20th and 21st centuries. Its significance is recognized by the international community: on June 7, 2024, the United Nations declared 2025 the **International Year of Quantum Science and Technology**, symbolically highlighting the global impact of this theory. This decision reflects a deep awareness of the importance of quantum science and its applications for the future of humanity. Through this global initiative, supported by leading scientific and academic societies around the world, awareness will be raised about the importance of quantum technologies in everyday life and future technological development.

The International Year of Quantum Science and Technology aims to bring together researchers, industry experts, students, and the general public on a global scale. This initiative will promote the advancement of quantum research and its applications in various fields such as quantum computing, quantum cryptography, quantum sensors and security, as well as quantum medicine and new types of communication. It also aims to inspire younger generations to engage in this exciting and important scientific endeavor that will shape the future.

The year 2025 was chosen not only because of the current progress in quantum science but also to mark the 100th anniversary of the emergence of quantum mechanics, one of the most revolutionary scientific theories in history. The International Year of Quantum Science and Technology represents an ideal opportunity to promote quantum mechanics and quantum physics, especially among young people, and to encourage future generations to engage in this exciting scientific field.

Research in the field of quantum mechanics has laid the foundation for the development of numerous new disciplines and technologies that shape modern science, industry, and all aspects of our daily lives. Some of the most significant applications include quantum information science, quantum computing, quantum metrology, quantum thermodynamics, the theory of decoherence, and quantum theory of open systems. These disciplines are deeply interdisciplinary, reflecting a trend in modern sciences and technologies, where collaboration among different fields leads to significant advancements.

In addition to its scientific significance, quantum science and technology hold exceptional potential for future technological development, with applications in areas such as communications, computing, security, and medical technologies. It is expected that the 21st century will be marked by rapid advancements in quantum technologies, and quantum

engineers and experts in quantum technologies will play a key role in shaping the future. In scientific circles, it is already predicted that this century will be defined as the era of quantum engineers and innovations in the field of quantum technologies (MILBURN, 1997).

Revolutionary concepts such as quantum superposition, the uncertainty principle, wave-particle duality, and the phenomenon of quantum tunneling are just some of the key discoveries that have transformed not only physics but also the way we understand reality. Although quantum mechanics continues to raise many philosophical and theoretical questions – particularly in the context of its integration with general relativity – it remains indisputable in its ability to describe, predict, and explain phenomena in the micro-world.

Today, quantum mechanics is not just a scientific theory confined to laboratory experiments – it is the cornerstone of future discoveries and technologies. By opening new paths in understanding the deepest principles of the universe, this theory continues to play a crucial role in our quest to comprehend the structure of reality, life, and the cosmos itself.

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