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De Broglie's Proposal Completes 100 Years Old

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ABSTRACT

In 1924 Louis de Broglie was the first physicist to formulate hypotheses about the wave behavior of matter. He used Einstein's mass-energy relationship and Planck's equation to describe how you can derive the wavelength of matter from its mass, velocity, and Planck's constant. Although this equation could not be well demonstrated, it was based on the assumption that matter behaved like light and had nanometer-scale wave properties. The wavelike behavior of light was proven three years later by two scientists who were able to observe that a beam of electrons diffracted when hitting a nickel surface which is exactly how an X-ray beam behaves in the same situation. This proof of the wave properties of matter validated de Broglie's equation and allowed the advancement of quantum mechanics.

Keywords: *Wave, Matter, de Broglie, Quantum Mechanics*

INTRODUCTION

The wave theory [1] states that light is a wave just as sound is also a wave. This model was based on Thomas Young's Experiment known as the Double Slit Experiment carried out in 1801 which involved the phenomena of diffraction and interference of light. The question was: how to explain the phenomena of

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diffraction and interference using the corpuscular model? Try as we might the corpuscular theory of light did not explain diffraction, that is, diffraction did not fit into the corpuscular model (1) defended by Newton. So the wave theory gained strength and followers at the time. Over time the wave theory was consolidated and, later, it was discovered that light was an electromagnetic wave that vibrated transversely in relation to its propagation. Therefore according to wave theory light is a wave of electromagnetic origin that propagates in any medium including a vacuum. In this model (1) light undergoes reflection and refraction as explained by Huygens' Principle.

On the other hand influenced by the work developed by the Greeks the English physicist Isaac Newton formulated a model to explain the nature of light, known today as "The Theory of the Corpuscular Nature of Light." This model of light consists of a flow of very small (microscopic) particles that are emitted by light sources. The idea of a particle really pleased Newton as it fit into his conception of the world, that is, a mechanical deterministic model of material bodies in motion where it would be possible to determine several quantities at the same time. Furthermore, through the corpuscular model of the nature of light, Newton was able to explain physical phenomena such as reflection and refraction, already known at the time. The great basis of support for the theory formulated by Newton was precisely the prestige he gained in the scientific society of his time and generations of scientists after him. Isaac Newton's work is considered one of the most beautiful scientific formulations ever created by man and certainly the corpuscular model was sustained due to this enormous prestige achieved. However not only fame and prestige conquered Newton. There were fierce scientific debates such as discussions involving Newton and his corpuscular theory mainly with his greatest enemy: Robert Hooke. From this scientifically troubled relationship with Hooke, the discussion about the nature of light arose.

ABBREVIATED BIOGRAPHY OF LOUIS DE BROGLIE

Louis-Victor-Pierre-Raymond, generally known as Louis de Broglie (1), was born on August 15, 1892 and died on March 19, 1987. He was a French physicist

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who contributed to the formulation of the theory of quantum mechanics. Louis de Broglie was born into a noble family in Dieppe on the Seine-Maritime, youngest son of Victor, 5th Duke de Broglie. He became the 7th Duke de Broglie on the heirless death in 1960 of his elder brother Maurice, 6th Duke de Broglie and also being physicist. He didn't get married. When he died at Louveciennes he was succeeded as duke by a distant cousin, Victor-François, 8th Duke de Broglie. Louis de Broglie initially studied history, then became interested in physics and mathematics, influenced by his brother, Maurice de Broglie, 6th Duke de Broglie and a prominent experimental physicist of the time. Louis de Broglie began his research work by studying X-rays, in collaboration with Maurice. It was this work that later led him to write his doctoral thesis, "Recherches sur la Théorie des Quanta". In this, de Broglie introduces his electron wave theory, which includes the wave-corpuscle duality theory of matter, based on the quantum theory proposed by Max Planck and Albert Einstein. This work opens up a new area of physics, wave mechanics, which constitutes one of the main bases of quantum mechanics. Louis de Broglie receives the Nobel Prize for Physics in 1929, for the theory of wave-corpuscle duality.

PARTICLE WAVE DUALITY

Louis de Broglie's doctoral thesis defended in 1924 constitutes a milestone (3) in the history of quantum theory. However de Broglie's first works in relation to light quanta were published in 1922 but it was only in 1923 that he attempted to make a synthesis between the wave and corpuscular theories of light.

As mentioned by JAMMER (4), Louis de Broglie's Scientific Itinerary in search of a causal interpretation for wave mechanics for material particles, the wave-particle duality that Einstein had proposed for light in 1905. For de Broglie the conditions Bohr-Sommerfeld quantization for electronic orbits could only be understood in terms of standing waves and it was this observation that led him to postulate the existence of matter waves.

The works published (4) in 1923 formed the basis of his doctoral thesis defended in 1924 at the Sorbonne in Paris with the title “Recherches sur la

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Théorie des Quanta", under the supervision of Paul Langevin. The importance of this work was soon recognized by Einstein who when referring to the quantum theory of ideal gas in his second work, drew the attention of other researchers to the idea that would revolutionize quantum theory.

De Broglie's hypothesis, by associating (3) each particle with a wave, influenced the German Erwin Schrödinger to write the equation for the propagation of matter waves. For Schrödinger the way de Broglie was able to explain the Bohr-Sommerfeld quantization conditions suggested the idea that quantization could be treated as an eigenvalue problem very common in the study of waves.

The formalism developed by Schrödinger (4) was very successful among quantum physicists as they were used to solving wave equations instead of diagonalizing infinite matrices as appeared in Heisenberg's formalism. In 1926, de Broglie published the article The Wave Mechanics and the Atomic Structure of Matter and of Radiation in which he presented for the first time what he called the "double solution principle". It consisted of considering that the matter wave propagation equation should admit two solutions one being the Ψ wave of a probabilistic nature (5) responsible for describing the behavior of a beam of particles and the other solution being a u-wave which as it contains a singularity would be responsible for describing each particle individually.

Due to the mathematical difficulties in proving the existence of the two waves and the relationship between them at the end of article he proposed a simplified version that he called "pilot wave theory" in which he assumed the existence of the material particle and the wave continuous represented by Ψ as having distinct realities and postulated that the movement of the particle is determined as a function of the phase of the wave Ψ through its guiding formula, that is, it would be a pilot wave the continuous wave responsible for directing the movement of the particle. De Broglie, when invited to present his work at the V Solvay Congress, in 1927, chose to use only the pilot wave theory in his communication entitled: La Nouvelle Dynamique des Quanta.

This communication did not receive support from the majority of those present at the congress, not even from those who still insisted on finding a causal

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interpretation for wave mechanics (Einstein, Langevin, Schrödinger and Lorentz). The group led by Bohr and Born defended the purely probabilist interpretation they had developed and refused to discuss the view adopted by de Broglie (1960). A notable exception was Pauli who criticized the theory presented by de Broglie citing the example of the Fermi rotor, which could very well be explained by the purely probabilistic interpretation, but which found difficulties in de Broglie's causal proposal. At this time, de Broglie did not have a clear understanding of all aspects of pilot wave theory many of which were only developed by Bohm in 1952.

EXPERIMENTAL CONFIRMATION

In 1927 Bell Labs physicists Clinton Davisson and Lester Germer performed an experiment in which they fired electrons at a crystalline nickel target. The resulting diffraction pattern matched de Broglie wavelength predictions.

De Broglie received the 1929 Nobel Prize for his theory (the first time it was awarded for a doctoral thesis) and Davisson/Germer won jointly in 1937 for the experimental discovery of electron diffraction (and thus the proof of de Broglie hypothesis).

Other experiments supported Broglie's hypothesis as true, including quantum variants of the double slit experiment. Diffraction experiments in 1999 confirmed the de Broglie wavelength for the behavior of complex molecules composed of 60 or more carbon atoms.

IMPORTANCE OF DE BROGLIE'S HYPOTHESIS

The de Broglie wave formula is one of the main tools in quantum physics (5) to describe the behavior of subatomic particles. It relates the energy and momentum of a particle to the wavelength associated with it, allowing us to understand how particles behave in different situations.

The application of de Broglie's formula is fundamental in several areas of science, such as particle physics, quantum chemistry and nanotechnology. It

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allows us to understand properties of subatomic particles and advance our understanding of the subatomic world.

In summary the de Broglie wave formula is one of the most important contributions to modern physics, and its application has allowed significant advances in our understanding of the world around us. The de Broglie's hypothesis showed that wave-particle duality (5) was not merely an aberrant behavior of light, but rather a fundamental principle exhibited by both radiation and matter. As such it becomes possible to use wave equations to describe the behavior of the material as long as the de Broglie wavelength is appropriately applied. This would be crucial to the development of quantum mechanics.

It is now an integral part of the theory of atomic structure and particle physics. The de Broglie relation regarding the dual nature of matter is applicable only to microscopic particles in motion. For macroparticles, the particle character is very large and the wave character is very small. In other words, the wavelength associated with these particles is so small that it cannot be measured by any of the available methods.

DEFINITION OF THE DE BROGLIE EQUATION

The de Broglie equation is an equation used to describe the wave properties of matter, specifically, the wave nature of the electron. In his doctoral thesis presented to the Faculty of Science at the University of Paris Louis de Broglie (5) proposed the existence of waves of matter. Any particle has an associated wave that governs its movement.

Combining the two momentum equations we have

$$\boldsymbol{p = mv \quad e \quad p = \frac{h}{\lambda} \Longrightarrow \lambda = \frac{h}{mv}}$$

where λ is the wavelength, h is Planck's constant and m is the mass of a particle moving at a speed v. De Broglie suggested that particles can exhibit wave-like properties. The de Broglie hypothesis was verified when matter waves were observed in George Paget Thomson's cathode ray diffraction experiment and in

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the Davisson-Germer experimente which applied specifically to electrons. Since then the de Broglie equation has been shown to be applicable to elementary particles, neutral atoms and molecules.

SCHRÖDINGER WAVE MECHANICS

Schrödinger (6) expressed the de Broglie's hypothesis about the wave behavior of matter in a mathematical form that is adaptable to a variety of physical problems without additional arbitrary assumptions. He was guided by a mathematical formulation of optics in which the straight-line propagation of light rays can be derived from the motion of waves when the wavelength is small compared to the dimensions of the apparatus employed. Similarly Schrödinger set out to find a wave equation for matter that would provide particle-like propagation when the wavelength became comparatively small (7).

According to classical mechanics (7) , if a particle of mass me is subjected to a force such that its potential energy is V(x, y, z) at position x, y, z, then the sum of V(x, y, z) and the kinetic energy $p^2/2m$ is equal to a constant, the total energy E of the particle. That is

$$\frac{p^2}{2m_e} + V(x, y, z) = E$$

It is assumed that the particle is bound, that is, confined by potential to a certain region of space because its energy E is insufficient for it to escape. As the potential varies with position two other quantities also vary: the momentum and therefore, by extension of the de Broglie relation, the wavelength of the wave. Postulating a wave function Ψ(x, y, z) that varies with position Schrödinger replaced p in the above energy equation with a differential operator that incorporated the de Broglie relation. He then showed that Ψ satisfies the partial differential equation (6)

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$$-\frac{h^2}{2m_e}\left(\frac{\partial^2\Psi}{\partial x^2}+\frac{\partial^2\Psi}{\partial y}+\frac{\partial^2\Psi}{\partial z^2}\right)+V(x,y,z)\psi=E\psi$$

This is the Schrödinger (time-independent) wave equation, which established quantum mechanics in a widely applicable way. An important advantage of Schrödinger's theory is that no further arbitrary quantum conditions need to be postulated. The necessary quantum results follow from certain reasonable constraints imposed on the wave function, for example, that it must not become infinitely large at large distances from the center of the potential.

ADDITIONAL CONSIDERATIONS

Erwin Rudolf Josef Alexander Schrödinger's (1887-1961) research on wave mechanics began in late 1925 as a development of his study of the 1924 thesis by Louis Victor-Pierre-Raymond de Broglie (1892-1987). It is well known that Schrödinger's wave equation can be derived from de Broglie's results, in the classical limit. From this point of view, one might think that Schrödinger's theory appears to be a mere development of de Broglie's theory. Schrödinger's wave equation can be derived from de Broglie's results in the classical limit. However, Schrödinger's theory is not an application or development of de Broglie's theory. Schrödinger's theory can be applied to cases where de Broglie's theory cannot be applied, such as accelerated motion and rotation, and to bound particles where the wavelength is comparable to the dimensions of the region containing the electron.

De Broglie's proposal has major philosophical implications for modern physics and has found expression in speeches, articles and books. The central question of his work was whether the fundamental probabilistic conditions for atomic physics were only so due to an ignorance of the underlying causes. In fact, they expressed ideas associated with the uncertainties of the act of measuring, which affects what is measured.

For about three decades after his 1924 work, de Broglie maintained his idea that implicit causes could not be drawn into a final sense. Instead, as time passed,

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he returned to his earlier belief that statistical theories hide a deterministic effect. In other words, there is a verifiable reality behind variables that escape our experimental techniques.

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