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The certainty of "uncertainty". Approaching the quantum world.

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Abstract
Quantum mechanics as a branch of physics developed in the early 20th century and describes the behavior of objects (molecules, atoms, particles) at the atomic and subatomic level. These objects are neither particles nor waves but "something else". They also have strange behaviors that no ordinary object is capable of replicating. Our understanding of the phenomena of quantum mechanics stands in profound contrast to our intuition and also to the visual representation of physical objects. Also, quantum mechanics is full of paradoxical mysteries and surprises that force us to conceive matter differently and "interrupt" the deterministic conception of classical physics. The atomic and subatomic world is perceived by assumptions of reasoning and measurements. Thus, we conclude that quantum mechanics interprets the microcosm and classical Newtonian mechanics the macrocosm without delineating the starting or ending lines of each part of physics.
***Key words**: quantum, particles, wave, Schrödinger, De Broglie, Planck, Heisenberg.*

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I. Introduction

At the end of the 19th century, classical mechanics gave the impression that it could explain all natural phenomena. It soon became apparent that this was not the case because too much experimental data could not be explained by such a theory. This fact prompted the development of a new physics, quantum physics, thanks also to the decisive contribution of various scientists such as E. Schrödinger, W. Heisenberg, P.A.M. Dirac and many others. In terms of quantum mechanics, it is a fundamental theory in physics that describes the behavior of matter and energy at microscopic scales, such as molecules, atoms and subatomic particles that are electrons and photons.

It has been about 90 years since the founding of quantum physics and quantum mechanics in particular. Almost all physicists recognize that quantum mechanics is absolutely correct and that it provides the basis for modern physics (Bosyk et al., 2019). However, quantum mechanics has the flaw of not forming an autonomous formalism. In most treatises on quantum mechanics, first, E. Schrödinger's equation is introduced heuristically with the help of the formulas Einstein and De Broglie, and then, "interpretations" are added which are required to understand the results obtained from its application to specific problems (Sakai, 2005). Such developments are useful in order to help readers learn quantum mechanics more quickly and easily as well as the concepts it introduces such as the concept of quantization, where certain properties, such as energy, can only receive discrete values.

In addition, Schrödinger believed that it is in principle impossible to formulate the basic concepts of quantum mechanics without the use of classical mechanics (Karam, 2020). Quantum mechanics, too, includes classical mechanics at the limit. At the same time, classical mechanics is the approximate theory of quantum mechanics, because quantum mechanics is reduced in classical mechanics to the limit at which Planck's constant approaches zero. Therefore, quantum mechanics must be established on its own proper basis independently of classical mechanics (Das Arulsamy, 2023). In order to position quantum mechanics as the foundation of modern physics in the true sense, it must be reconstructed from "quantized" mechanics to real "quantum" mechanics. This means that real "quantum" mechanics must not be based on classical mechanics that approaches quantum mechanics. Finally, condensed matter physics and nanotechnology reduce the gap between classical and quantum domains in the practical realm (Craig et al., 2021).

The usefulness of quantum mechanics extends to various fields, including atomic, molecular, and optical sciences, as well as nuclear physics. It provides methodologies to address complex problems in these areas, such as atomic structure, spectroscopy and quantum information processing. Quantum mechanics also plays a key role in the development of technologies such as superconducting quantum circuits, which are based on the principles of quantum energy and quantum state manipulation.

These developments require, and at the same time require, more and more qualitative education in quantum mechanics both in universities and secondary schools, with emphasis on a clear and stable approach – understanding of the subject. For this reason, we focus on briefly presenting examples of natural experiments where classical theory fails to predict the correct outcomes. These results are used as cornerstones, defining the principles upon which quantum physics rests and is based.

1.The principle of superposition

Let's take a quantum object, for example, an electron. This particle is in several places at the same time. Many such particles form a kind of cloud around the nucleus, the quantum cloud, and are constantly in all places at the same time, with well-defined probabilities. We cannot, therefore, speak of position or velocity for a particle but only of probability density of presence (Fenwick & Dick, 2023)**.** So, no one can tell us where an electron is at a given moment (Annual IEEE Computer Conference et al., n.d.).

According to Louis De Broglie, the electron acts as a wave but also as a particle. Thus, it can be in different places and at different speeds. Indeed, a wave is not detected in a single place, like an object.

If I throw the electron at the wall, it bounces. Normally if I throw it at a thin wall, it will most likely end up on the other side of the wall, as if it has been teleported or crossed a magic corridor. This is the "tunnel effect (Castro et al., 2018)". No, but it's right on the other side.

The concept of superposition defines that a quantum, connected to the smallest unit of energy can exist, is as if floating in several realities, which indicates that it is moving at many speeds and is in many places (Kim, 2023). This is on condition that neither its speed nor its position is measured. The above probabilities can be calculated with enormous precision thanks to Schrödinger's wave function. Moreover, "His equation is an elegant construct (Dalla Chiara, 2010)."

In a quantum system, a single wave particle can be found in a coherent superposition of states which carries the possibility of all possible states. His presence in a given place, his energy, then becomes then, probably logical. Thus, an atom can be both in its stable fundamental state and in an excited state which possesses higher energy and is obtained by absorbing a photon. A photon can be in one place and in another at the same time. Only if we measure can we be sure that it is in one place. The measurement procedure then imposes a definite state on the particle wave.

It is very easy to produce particles, such as photons or atoms that are in a superposition state. There is even the snowball effect, when one particle collides with another particle or atom. Then, the whole is immediately in a state of "superposition" and one can calculate with great accuracy the probabilities of the presence of the new in some place. This characterizes the wave function, which is a kind of field regulated by a function for energy and denoted by a mathematical tensor (Li et al., 2023). When applied to the atom, the equation gives a few solutions, each of which describes a static model of the field, the energy states of the atom (Dalla Chiara, 2010). When we try to measure the particle, it shrinks to one point, between all possible parts. The electron (particle) "draws" according to the probabilities each time we measure it and really its position is random.

When the particle is measured, the "superposition" of the states collapses. The act of observation by an observer causes the wave function – which extends across space – to a single point, where the observer saw the "electron". Thus, the simple act of measuring by an observer disrupts all probabilities instantaneously, throughout space and reduces them to zero except for one point (Xin & Xin, n.d.).

To describe a state I use the symbols \>. As far as the superposition state is concerned, I add the states. So Schrödinger's cat can be a quantum superposition of a living and a dead cat. However, nothing is known for sure about the principle of superposition. The symbols we use in quantum mechanics are \ >.

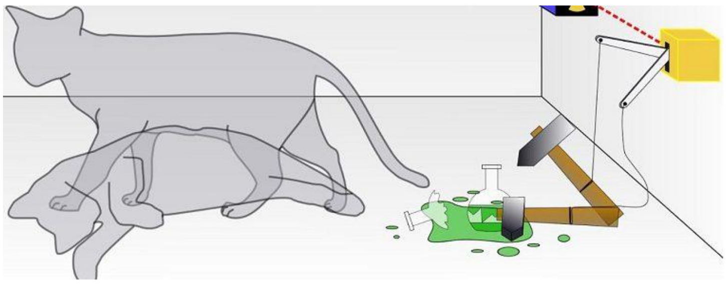

Figure 1: *Schrödinger's cat* (Griffiths & Schroeter, 2018).

So, I will have: \cat> =\dead >+\alive>. From the very superposition of situations derives all the strangeness of quantum mechanics.

2. The indeterminacy of measurement.

In classical physics it is easy to measure the position and speed of an object such as a soccer ball.

In quantum mechanics, as mentioned, the electron is simultaneously in many positions. Suppose an electron moves at 1,000km/h or 2,000km/h. How can we measure its speed? We have \electron>=\1,000km/h>+\2,000km/h>. If we measure the speed, we will find 1,000km/h or 2,000km/h or some value between the two values. Quantum mechanics tells us that we will find either one value or the other, but we cannot know in advance which of the two. If we repeat the measurement several times, we will not find the same result as the previous measurement. In fact, in the measurements we will find for 50% speed values equal to 1000km/h and for the other 50% speed values equal to 2000km/h. However, we can also have variations of this situation, (1/4 \ 1000km/h> +3/4\ 2000km/h>. That is, the electron is three times in the state of 2000km/h. This changes the probabilities of the measurement. The above example refutes the deterministic concept of classical physics. Of course, theoretically, the existence of solutions by Heisenberg or Schrödinger leads the "framework" to a mathematical formalism and a "peculiar" determinism.

Differently and as characteristically stated, while giving the impression of "randomness" in quantum mechanics, "but in essence it is not, since a deterministic equation can be written that predicts it (random) (Laloë, F., 2008)". In quantum mechanics there is a fundamental spontaneity that makes the outcome impossible to predict. This idea shocked Einstein who did not accept it, through the expression: "God does not play dice (Sid-Ahmed, 2011)". In other words, he refused to accept that chance plays a fundamental role in physics. Yet he was wrong (Elitzur et al., 2012).

3.The wave-particle duality.

The British physicist T. Young (1773-1829) formulated the wave theory between 1799 and 1804. Light according to Young was a wave phenomenon like sound. That is, it is a disorder that travels through space. Max Planck (1858-1947) in 1900 and Albert Einstein (1879-1955) in 1905, studying the behavior of the atom led to the conclusion that energy was not a continuous quantity but consisted of discrete quantities, the so-called quanta (Singh, V. (2005).

That is, at the subatomic level hot objects could emit energy in small quantities or "packets". Planck claimed that the amount of energy in a quantum increases with its frequency. A low frequency, such as red light, has less energy than a high frequency such as white light. However, Planck could not explain why energy was "quantized" in this way (De Andrade et al., 2023). The answer came thirteen (13) years later from Niels Bohr. Before Bohr, quantum theory solved another problem, the photoelectric effect. This phenomenon is linked to the fact that light incident on a metal surface can cause electrons to be ejected from the metal.

Classical physics describes light as a wave. The interpretation given by Albert Einstein is that, in many cases, light behaves as a packet of electromagnetic energy (photons). Bohr, then, in 1913, determined after studies, the structure of the atom. More precisely, he argued that in the classical model, with a positively charged nucleus and negatively charged electrons moving in orbit, electrons must flow in a set of orbits. He called these electrons orbital electrons, and each of them is connected to a specific energy level.

When an electron absorbs enough energy, it jumps from one energy level to the next, which is larger in diameter. When an electron "falls" from a higher to a lower energy level, it emits energy that corresponds exactly to the energy difference between two energy stations. This is why energy exists at discrete values, such as quanta, and not on a continuous scale (Silva et al., 2020).

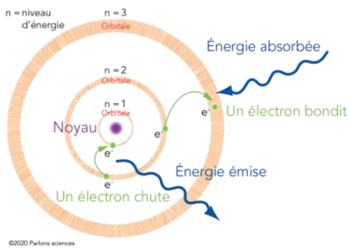

Figure 2: *Bohr model of the atom: Electron energy transitions* (Griffiths, 2005).

The French physicist Louis de Broglie simply makes a synthesis of Einstein's equation $E=m\cdot c^2$ with Planck's equation $E=h\cdot f$ and calculates for each moving particle a wavelength (Logiurato, 2014).

After many reservations of scientists and with the positive intervention of Einstein, De Broglie explains his point of view to a wide audience of scientists. "For more than half a century we have divided the phenomena of the world into two sectors. More precisely, in the atoms and particles of solid matter and in the immaterial waves of light, which spread in the sea of light ether. But these two systems must no longer be considered separately, we must unite them into a single theory. Only such a theory can explain his multiple interactions (Eisberg, R., 1985)." Based on a random event in April 1925 with physicist Davidson, De Broglie's studies verified that electrons can, depending on the circumstances, behave like waves (Matteucci et al., 2009).

Thus, the wave and the particle are not opposing views, but complementary. They are two views embodied in reality, like two sides of the same coin (Knight, 2020). However, each of the two sides does not constitute the coin, but both together constitute it. The sides of a coin complement each other and merge into this concept of the coin that is true.

4. The tunnel effect

As a point of reference we take an example according to which the sheet metal of the neighborhood hits a sheet metal and produces a series of sound waves. Although the house is "shielded" from external noise, some of the sound will pass into the house. The sound will be faded or even very faint, but even a small part of it will pass. So, let's imagine now, an electron reaching an obstacle (a thin wall). When electrons are described as a wave a part of them, like the sound of hammering, will pass through the other side of the obstacle. The wave-like nature of the electron describes a probability of finding electrons in a given place. Thus, there is a chance – even a small one – that the electron will cross the obstacle.

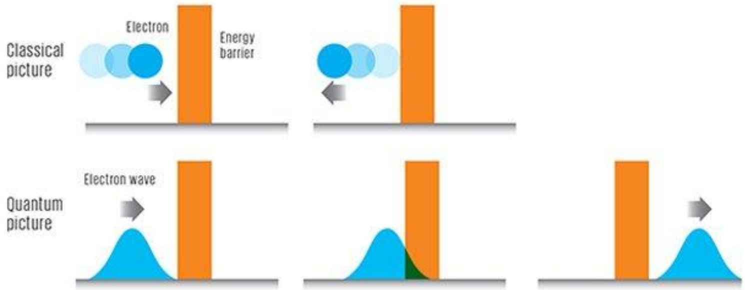

Figure 3: *Quantum tunneling - Classical physics vs. quantum perspectives* (Griffiths, 2005).

We talk about the tunneling effect, because everything happens as if a small tunnel is created in the wall for our electron to pass through. The tunneling effect is an example of what may be happening in the microcosm of the quantum world but not in the macrocosm (University of Illinois at Urbana-Champaign, 2015).

5. The double notch

The nature of light has been a puzzle for natural researchers over the centuries. Newton and most 18th century physicists claimed that light is particle. In the early 20th[century], studies and research showed that light consists of energy quanta now called photons (Buenker, 2022). Photons have the ability to "hit" and expel electrons from atoms. Also, we can count individual photons as they hit a sensitized plate. Thus, the light seems to behave like pellets fired from a gun.

In 1803, Thomas Young pointed out that light is also made up of waves. He did the famous experiment with two notches or two slots. If the particles were pellets, they would pass through the slots, hit the opposite distant wall, and land in the two obvious areas of the wall. Instead, Young found a strange shape of light and dark streaks which, he claimed, could only be caused by wave-like interference (Schatten, 2023). So, one could very well argue that light is a wave. Yet today's variations of the experiment prove something amazing, namely that even individual photons are affected by the interference wave. However, a separate photon would only have to pass through one slit.

That is what our logic says. The photon, however, also comes from two slits. Imagine someone coming out of both the front door and the back door at the same time. How can this behavior be explained? According to the uncertainty principle, a particle does not always reveal properties such as its position and velocity. Properties appear only when they are measured. So, each unmeasured particle could take in a large number of paths simultaneously. The particle seems to take both paths until we measure it and say that it passed through slit A. Let us take this measurement and put an observer behind each slit. According to the "Copenhagen interpretation", the introduction of observation of a particle in the experiment "forces" the particle to choose one of several possible quantum states (Gomatam, 2007).

Physicist Feynman reached this idea at its peak, writing that when a quantum particle goes from one point to another, it takes all the possible paths connecting those two points (Preskill, 2021). This approach is known as integral paths.

6. Heisenberg's uncertainty principle.

The uncertainty principle is one of the most characteristic and paradoxical properties of the quantum world. At the beginning of the superposition of molecules, atoms and particles, it seemed that we can superimpose anything and everything. In fact, this does not correspond because there are limitations.

Particles have certain pairs of properties such as, position-velocity, energy-time, rotation-angular position that are "complementary. That is, one property complements the other. In practice, this means that you cannot make accurate measurements of both properties. The more you learn about one, the less you learn about the other (Griffiths & Schroeter, 2018). One cannot measure with arbitrary precision two coupled variables such as, position and momentum, angle of rotation and angular momentum or energy and time. In classical physics there was the problem of uncertainty to a large extent but, Physicists attributed the problem to the inaccuracy of the instruments and predicted that, in the future, they would solve the issues with more accurate instruments (Wulandari, 2023). Heisenberg's principle points out that uncertainty is not a mistake but a law of nature.

The wave-particle duality causes headaches for physicists (Camilleri, 2006a). In 1926, Albert Einstein wrote in Paul Ehrenfest that, "When waves, sometimes quanta! The reality of both is unshakable. But "the devil plays bad games (Unna & Sauer, 2013)." In classical physics the world was still in order, which is confirmed by the fact that there were waves and there were particles. When it comes to the quantum world, particles sometimes look like waves. But maybe it's the other way around. Heisenberg took particles for granted in his quantum mechanics, and Schrödinger imagined the world as a large set of waves. These two mathematical approximations, although the starting points were seemingly incompatible, proved mathematically equitable (Camilleri, 2006b; Volodymyr & Ukraine, n.d.) Heisenberg's particle mechanics and Schrödinger's wave mechanics proved equivalent, but failed to solve the problem of wave-particle duality. Thus, it turns out that electrons "fooled" the researchers. That is, as long as one does not look at them, they are waves. However, once one looks at them, they are particles (Schatten, 2023). In quantum mechanics, once we describe particles as waves, we can't determine their position or speed. With Heisenberg the laws of uncertainty are established and the laws of causality of classical physics are set aside, and as he characteristically said: "darling, I parked the car, but I don't know where? (Bosyk et al., 2019; Dalla Chiara, 2010) ».

Inference

As Heisenberg said, "No one can observe the world without changing it." So, he was led to quantum mechanics from where he wanted to study the world. The general postwar environment (after World War I) favored the "natural" redefinition of scientists to lead them to new natural adventures, such as these theories of relativity and quantum mechanics. The deterministic and deterministic conception of Newtonian physics "led" to the interpretive absolutism of natural scientists. According to her, physical laws can now explain all the phenomena of the universe and the authorities founded the ultimate expression in natural science in construction (tools, machines, weapons systems) resulting in the global destruction of vision before World War I. Quantum mechanics now requires a systematic review of cause and effect (Gachechiladze et al., 2020). Her new theories destroyed the deterministic conception of classical physics and paved the way for man's "holistic" approach to nature. The positions, the contradictions, the rivalries, the transcendences in the thought and vision of a multitude of young (very young) natural scientists created in the early 20th century an amazing creative scientific environment with the expectation to solve the issues of nature's functioning in the microcosm. Eventually, they achieved this both theoretically – albeit with risky views – but also technically by creating new tools for interpreting and well-being people's lives. and the conception of nature's new function. As Niels Bohr famously stated, "It cannot be our job to define how God should rule the world (Morita, 2020)."

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