Manifestation of Quantum Mechanics And Particle Physics In The Macroscopic World

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ABSTRACT

Since the discovery of quantum dynamics in the 1900s, we have observed many of its effects on the macroscopic world. Max Planck gave the first quantum hypothesis in 1900, explaining how electromagnetic waves transmit energy in “quanta.” Building upon that, Louis De Broglie stated the theory of wave-particle duality, and Erwin Schrodinger postulated the equation to interpret this wave nature. Physicists expanded the field as the theories of Quantum Electrodynamics and Quantum Chromodynamics were put forward, explaining the Electromagnetic Force and the Strong Nuclear Force in terms of quanta. Theories such as the Many Worlds Interpretation were also proposed to explain quantum mechanical phenomena. Although there were many discoveries, there were also problems such as the Hierarchy Problem that arose because of the unusual mass of the Higgs Boson. Nevertheless, This unusual mass of the Higgs needs to be “unusual” for life to exist. If it were something else, the discovery of Quantum Mechanics would not have been possible, and everything we have learned about it till now would not exist; we would not exist. Thus, we can look at how quantum dynamics affects the macroscopic world even though it governs the world of the “very small.”

Introduction

Quantum Mechanics and Particle physics have come a long since their advent in the 1900s. Max Planck gave the first quantum hypothesis in 1900, which described that energy was emitted and absorbed in discrete packets or quanta. Then in 1905, Einstein used Planck’s hypothesis to explain the photoelectric effect: emission of electrons when light hits a metal surface. Later in 1923, Louis De Broglie stated the theory of matter waves that particles have dual nature: wave nature and particle nature. Erwin Schrodinger introduced wave mechanics, and Bron put forth the probabilistic interpretation of Schrodinger's Equation, the final touch to Quantum Mechanics, which was later widely accepted at the fifth Solvay Conference (1).

Quantum mechanics and the world of particle physics is the world of the very “small.” This world, where we consider particles smaller than atoms, is not simple in any sense. Particles exhibit phenomena such as superposition: they exist at multiple physics states at the same time. For example, a particle is not even in one place; it only has a probability of being there. There are not just protons, neutrons, and electrons here, but also particles that make up the protons, neutrons, and many others. Strangely, the world we live in is not anything like this: we cannot be at two places at the same time, and we cannot have a probability of having a variety of different energies. We live in a continuous yet discrete world that has perceivable outcomes. Although Quantum mechanics is bizarre, when looked at from the perspective of our experiences, they manifest and govern the macro world.

Discussion

Basics of Quantum Mechanics

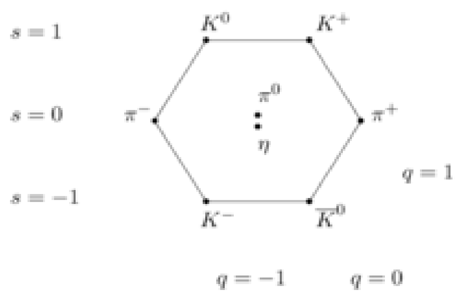
Erwin Schrödinger formulated the quintessential equation of quantum mechanics: Schrödinger's equation ($E\Psi = \frac{p^2}{2m}\Psi + V(x)\Psi$). It is a linear partial differential equation used to calculate the wave function, which pertains to the probability distribution of a quantum system(2). Schrödinger's equation equates the total energy of the system as a sum of its Kinetic Energy and Potential Energy represented by $\frac{p^2}{2m}\Psi$ and $V(x)\Psi$, respectively. Schrödinger's equation is the quantum mechanical version of Newton's Second Law(F=ma): which tells us how a physical system evolves. Schrodinger's equation is Newton's second law's quantum counterpart, and it tells us how a quantum system will evolve in time. When physicists calculated the wave function, they found out that the equation had multiple solutions. These solutions did not have any meaning at first; Schrödinger first interpreted these solutions to be the electron's position. However, Born found out that the square of a solution to the wave function calculated from Schrödinger's equation gave the probability of a quantum system being in that state if measured. If no measurement is made, then the system is in a quantum superposition. Of all the possible states, the system simultaneously exists in all possible states with some probability.

It was surprising to scientists that nature was non-deterministic at the most fundamental level. They also thought that the idea of superposition was absurd. They devised a thought experiment in 1925, now known as Schrödinger's Cat(3-4). The experiment was devised as follows: Consider a box with a cat in it. The box has a radioactive atom that can decay and a detector which will detect if the atom has decayed or not. The detector is connected to a trigger system that will release a poisonous gas. If the detector indicates that the atom has decayed, the trigger system will release the poisonous gas, and the cat will die. However, if the detector indicates that the atom has not decayed, the trigger system will not release the poisonous gas, and the cat will stay alive. Now, if the system is quantum mechanical, the atom will be in a superposition of the decayed state and the undecayed state; therefore, the trigger system will release the gas and not release the gas simultaneously; this makes the cat in the box in a superposition of the state of being alive and the state of being dead, that is, the cat is alive and dead at the same time. This is not what we experience or can experience as reality; there cannot be something living that is alive and dead simultaneously; the cat cannot be alive and dead simultaneously. To bridge the thought experiment and reality, scientists explained the experiment with something more. To check if the cat is dead or alive, you need to open the box in the experiment. The act of opening the box would make you the observer part of the cat box quantum system because by opening the box, an "observation" was made. This act will collapse the wave function, which had two possibilities before, to have one state: either the cat is alive or dead. There is one more possibility: it can also happen that before you opened the box, the wave function of the cat already collapsed to one of the two possibilities. It could have interacted with its surroundings that caused one of its superpositions to cease to exist, a phenomenon known as decoherence (5).

Quantum Electrodynamics and Quantum Chromodynamics

The fact that light is an electromagnetic wave was known to physicists for a long time. Thomas Young performed the double-slit experiment to prove that light behaves like a wave. In the experiment, he passed a beam of light through two thin parallel placed slits. When the light passed through the two slits, it formed a diffraction pattern on a screen in front of the two slits. The diffraction patterns are only created when waves interfere with each other constructively and destructively.

Light also had a particle nature, which was demonstrated by the Photoelectric effect. The photoelectric effect is observed when light is shone on metal. The light falling on the metal ejected electrons from the metal. The wave interpretation of light could not explain this phenomenon. If light is a wave, the energy of light will depend on the intensity of the light. If light were a wave, the energy of the ejected electron would increase as the intensity of light increases. Still, experiments showed that increasing the intensity only increased the number of electrons ejected, not the energy of each electron. Albert Einstein used Planck's quantization of electromagnetic radiation to hypothesize that energy in light is contained in discrete packets or "quanta", this quantum of light was later called the photon. Einstein stated that energy could only be transferred in integral multiples of this quanta and related to the frequency of light multiplied by Planck's constant, $E = hf$. It was later experimentally proven by Robert Andrews Millikan that the frequency of light was indeed linearly related to energy. These achievements and further efforts by physicists helped us formulate the theory of Quantum Electrodynamics, the theory of interactions between charged particles via the exchange of photons.



After the development of Quantum Electrodynamics, physics began to focus on other discoveries of new particles. Scientists had discovered many particles called hadrons with the use of bubble chambers and spark chambers in the 1950s. Then number and apparent similarities indicated that they were not fundamental particles. To better understand the hadrons, they were sorted into groups with similar properties and masses using the eightfold way, which categorized particles based on their charge and strangeness number (a Quantum number given to each particle by the physicists), postulated in 1961 by Gell-Mann(6). With the help of George Zweig, Gell-Mann went on to propose in 1963 that the structure of the groups could be explained by the existence of three smaller particles inside the hadrons: the (up, down, and strange) quarks. Later in 1973, physicists developed the concept of color-charge (particles were not actually carrying color, they just call the charged color because we associate the world charge with electromagnetism) as a source of a strong force into the theory of Quantum Chromodynamics. Physicists employed the general field theory in which the carrier particles of a force can interact with other carrier particles. This was different from Quantum Electrodynamics, where the photons that carry the electromagnetic force do not interact with other photons. Physicists also noted that these quarks might interact via another quanta like the photons, called gluons. Evidence of gluons was discovered at the three-jet events at Positron-Electron Tandem Ring Accelerator in 1979. Thus, The Theory of Quantum Chromodynamics came into being, which describes the Strong Nuclear force as a force acting between Quarks and is mediated by the gluons.

With these two Quantum Field theories, now let us take a look at an atom. The atom is composed of protons, neutrons, and electrons. Protons and Neutrons are made up of quarks: the up quark and the down quark. The electron only interacts with the photon, whereas the quarks interact with both gluons and photons, thus experiencing both the electromagnetic force and the Strong nuclear force. These characteristics are necessary for the atom to exist and what we call "matter" to exist. Protons and neutrons are kept glued together in the nucleus with the strong nuclear force with the exchange of gluons. Electrons keep orbiting the nucleus due to the electromagnetic force acting on it as the quarks in the nucleus are interacting with the electron via photons. These constant interactions among quarks and between quarks and electrons make up a stable atom.

Many Worlds Interpretation

Quantum mechanical phenomena are observable on the level of atoms and electrons only. As the size increases and we reach the macroscopic world we live in, we cannot observe quantum mechanical phenomena such as superposition and probabilistic determinism. There is a concrete line between "Yes" and "No", "Here" and "There" in the Real World (macroscopic), but in the quantum mechanical world (microscopic, around the size of electrons), this concrete line becomes fuzzy or sometimes is not even there. There is a sudden jump from quantum to reality. Many theories have been trying to bridge the quantum mechanical and the macroscopic world, one being The Many Worlds Interpretation. It creates a connection between our experiences and the Quantum Universe (7).

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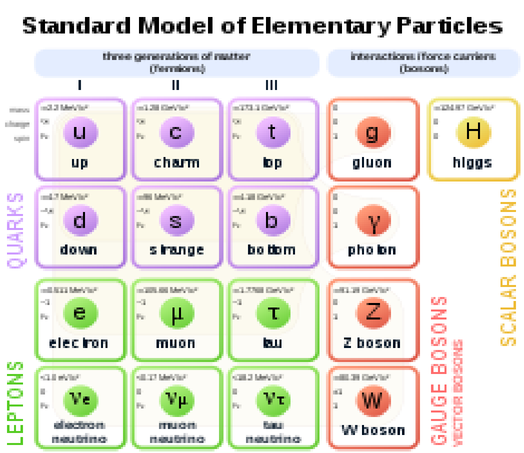
The many-worlds interpretation was first proposed by Hugh Everett (8). The theory states that when a Quantum Measurement is made, according to Schrödinger's equation, there is no collapse of the wave function but rather both or any of the possibilities of the system states that are possible occur at the same time, that is it exists in a superposition of the multiple states. For our real-life experiences, the theory would fit in a way such that everything around us and we are in a state of superposition. There are no physical duplicates of the worlds or people. It is just that particles making everything up are entangled and in a state of superposition. It is similar to multiple realities overlapping with one another rather than being separate, complete worlds. It is like there are "virtual phantoms" of everything that we cannot see, but they all do exist, abiding by Schrodinger's equation and the laws of Quantum Mechanics.

Anthropic Principle and Hierarchy problem



The Standard Model represents years of research and discoveries of physicists. It is the catalog of known fundamental particles and forces. This table had been incomplete until 2012 when we discovered: the Higgs boson. The Higgs had been predicted by Peter Higgs and others in 1964 to explain why particles have mass. The discovery of the Higgs by the LHC completed the Standard Model. However, the mass of the Higgs at 126 GeV was unexpected. Quantum mechanics would lead us to expect the mass of the Higgs to be either zero or near to Planck energy, which is 10■^{15} times larger than its observed value(9). This is the Hierarchy problem: the vast discrepancy between what we expect the mass of the Higgs to be and what it is observed to be.

A possible solution to the Hierarchy Problem is the Anthropic Principle. The principle states that whatever exists, exists for a reason. The underlying factors that let us exist and carry out all these experiments and discover the truths of the universe must be what they are; Otherwise, we would not even exist to know these parameters. The Higgs mass must be negative and close to its observed value for life to exist (10). The observed value of the Higgs mass makes "complex chemistry"; chemical compound formation and chemical reactions; possible, which is necessary for life. The Higgs mass is proportional to the masses of all the fundamental particles, and if the Higgs mass had been something else, there would be no proportionality, or the fundamental particles would change themselves, making the universe not suitable for life. Thus we can argue that the Higgs parameter needs to be its observed value and nothing else for life to exist.

Conclusion

All Quantum Mechanical features and theories define the world of the "very small", but they justify and govern the macroscopic world. Using the many-worlds interpretation, we look at the basics of quantum mechanics and Schrodinger's Equation to theorize that the atoms and matter we are made of are in a state of superposition, and there are multiple realities because of it. We cannot interact with these superpositions or even experience them; they exist as realities where the wave function evolves differently. If we look at these atoms that occur in these realities, they are further composed of protons, neutrons, and electrons. The electron itself is a fundamental particle and cannot be divided further, whereas the proton and neutron are composed of quarks. These quarks are held together in the nucleus of a stable atom because of the Strong Nuclear force which is mediated by the gluons. The quarks and the electron pull on each other because of the Electromagnetic Force which is mediated by the photons, keeping the electron in orbit and the atom stable. The quarks and electrons exist because the Higgs Boson gives them mass. Although the mass of the Higgs itself is unusual, it needs to be its observed value for life to exist. If it were something else the fundamental particles and forces that keep an atom stable would. No stable atoms would mean no real matter, which means no life. Thus, we can say that even though quantum dynamics defines the world of the “very small,” it justifies the existence of the macroscopic world.

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