Quantum Physics

A Beginners Guide to How Quantum Physics Affects Everything around Us

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Introduction

I want to thank you for choosing this book, '*Quantum Physics - A Beginners Guide to How Quantum Physics Affects Everything Around Us*' and hope that you find this book informative and interesting in your quest to understand Quantum Physics and the role it plays in our everyday life.

Since you have chosen this book, it is certain that you have an interest in the field of quantum physics and look forward to understanding the concept better. For most of us, quantum physics is a complicated labyrinth that is meant for the geeks of the world; however, there is no denying the fact that the theories of quantum physics are extremely exciting.

Quantum physics as a term was not exactly a part of our daily parlance, but the Sitcom – The Big Bang Theory changed it all. When the characters in the series started to throw around big quantum theories and other scientific terms casually, a lot of us realized that quantum physics actually has a much stronger influence and role in our lives than what we actually know. I am not saying the show is the best place to start understanding quantum physics, but it can definitely be credited for making Quantum physics interesting to the layman, with no background in physics.

When we hear the term quantum physics, the first thought that comes to our mind is Einstein and his theory of relativity. Of course, it goes without saying that there is much more to quantum physics than that. Physics is an excellent medium of explaining a million different things starting from heating a cup of coffee to gravitational pull. There is no real limit in the discipline of physics. It involves matters that are as huge as the galaxy to things as small as neutrons. This book deals with the smallest side of it, which is the branch of quantum physics.

Throughout the course of this book, you will get a much better understanding of quantum physics starting from the basic concepts to some in-depth information. You will also see a lot of math and calculus in the book since quantum physics uses many concepts from those subjects. Don't dread reading through even though it might sound dreary and difficult. I don't intend to scare you with big equations and calculations, as this book will not make you a physicist. The sole aim of this book is to simplify quantum physics for the common man, who has no idea what it entails and how it affects our everyday life.

I have put the text together in a way that should make the subject matter much simpler to understand and maybe interesting to someone who normally hates science. I assure you that by the end you will have learned more than you normally do by just staring blankly ahead in a classroom. And if you are a curious student, you will definitely know more about quantum physics than before.

Quantum physics deals with the movement of microelements like electrons. Physicists have spent a lot of time and effort over the years in order to get this kind of in-depth knowledge of quantum physics. The branch of quantum physics is related to the smallest particles of matter or energy that exists. This is a more in-depth study than classical physics. As quantum physics has developed over the years, it has been able to explain the certain phenomenon that classical physics could not properly account for. Scientists took great interest in finding out more and correcting old norms, which were not essentially correct.

A lot of research has been and is currently being conducted in order to make quantum mechanics operational in our daily lives. For instance, if a proper quantum computer is made available to people, it will be able to solve many problems in a fraction of the time that it takes our standard computers. Such developments in the field of science are what will change the future. Quantum mechanics are also believed to be a crucial part in creating artificial intelligence. Complicated matters like national security will also benefit majorly from progress in quantum mechanics in cryptography. There are many such advantages that quantum physics can grant the world. You should learn more about it just like the scientists dedicating their lives to its growth.

Like I mentioned, this book is not meant to make you a physicist and is definitely not meant for you if you have a background in quantum physics. It intends to simplify the concept of quantum physics, which have been an enigma to the layman without a physics background. The things that you will learn in this book will definitely make you wiser in understanding how the world around us functions and the role quantum physics plays in making it work. One thing I can assure you is that by the end of the book, you will definitely feel smarter than before and will improve your general knowledge in things related to quantum physics.

Without further ado, let us take a deep dive into quantum physics and how it has a role to play in just about everything we do. I thank you once again for choosing this book and hope you find it an interesting read.

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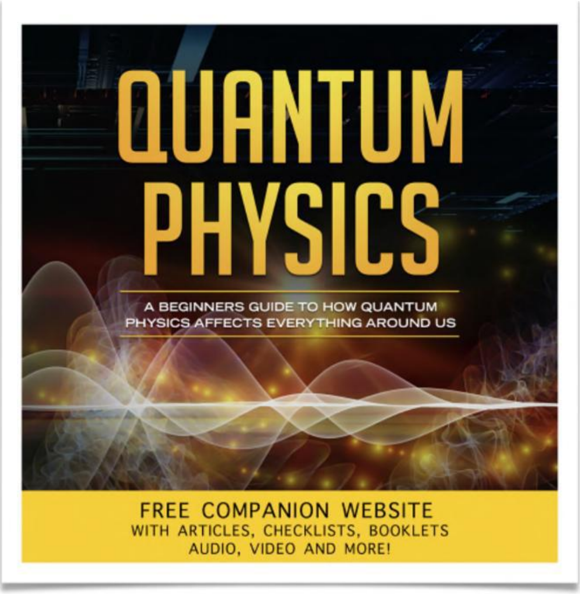

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Chapter One: What is Quantum Physics?

Let us first understand what quantum physics really is. The word “quantum” is derived from Latin and means “how much”. So, the quantum is in reference to the smallest particles of energy as well as matter that are studied in physics. Quantum physics is the branch that studies the conduct of the minutest levels of matter and energy. This is at the smallest microscopic levels including molecules, atoms and nucleons. It is important to separate this from the larger picture because it was proven that the laws for macroscopic objects are not the same for microscopic objects. Quantum physics also emphasizes on inter-particle interaction as well as electromagnetic radiation.

The development of the field of quantum physics can be attributed to people like Albert Einstein, Max Planck, Werner Heisenberg, and many others. Max Planck wrote one of the more prominent papers that contributed to its birth on blackbody radiation. This was as early as the start of the 1900’s. Neils Bohr and Richard Feynman were also major contributors in this field. In fact, Johnston first used the term “quantum physics” in “Planck’s Universe in Light of Modern Physics” in 1931.

Quantum physics is also called by other names such as quantum mechanics or even quantum field theory. This science has many subfields, but it is broadly known as quantum physics when it encompasses it all. It is also known as matrix mechanics or wave mechanical model. All this basically means the physics of the smallest atomic or subatomic levels of particle energy. Quantization, Wave-particle duality and the Uncertainty principle are very important aspects of quantum physics. The quantization principle explains how the momentum, energy and angular momentum as well as other properties of any bound system will be restricted to some discrete values. The wave-particle duality principles refer to how objects will have the characteristics of both particles as well as waves. The uncertainty principle states that there are certain limits to measuring quantities precisely.

Quantum physics is different from classical physics because the former deals with nature at a macroscopic level. Until quantum physics was developed, everything derived from classical physics would relate to the larger scale of matter. This branch of physics studies the elementary parts of matter. We learn the difference between the behavior of particles in an object and the behavior of the object. The quantum theory attempts to explain this unique behavior of matter and energy at a subatomic level. It also helps a great deal in understanding the behavior of particles that move at the speed of light or such extreme speed.

One of the key points in quantum physics is that it emphasizes that the observation of physical processes actually influence what takes place. The wave-particle duality tells us how light waves act as particles and particles can act like light waves. We learn about quantum tunneling through which matter goes from one spot to the other without travelling through the intervening space. Information can be passed in an instant through a vast distance. Quantum mechanics helps us realize that everything in the universe has many probabilities. It is just easier to deal with things on a larger scale than with smaller details.

Under quantum physics, various branches are singularly worked on. Consider the branch of Quantum Optics. In this, a scientist tends to focus on the behavior of light and photons. Unlike the concepts developed by Sir Isaac Newton in classical physics, quantum physics shows that the behavior of each individual photon will have an effect on the overall light. In fact, this branch is what helped in the development of lasers as an application. Under Quantum Electrodynamics, we study the interaction of photons and electrons. Many scientists are trying to merge the concepts of quantum physics with the theory of general relativity. This is called the unified field theory. Some of these unified theories are Quantum Gravity, Grand Unified Theory, Loop Quantum Theory, String Theory, and the Theory of everything.

Another thing to keep in mind regarding quantum physics is that it is probabilistic. This is also the most controversial aspect of it. It is actually impossible to predict the outcome of any single experiment on a quantum system with absolute certainty. The outcomes of these experiments are predicted by keeping probabilities in mind for different outcomes. Repeated experiments are used to deduce the most probable outcomes. The "Born Rule" plays an important part in these cases but it is still being worked on to find something more absolute.

For the most part, quantum phenomenon is usually confined to the scale of atoms or fundamental particles. This is so that the mass and velocity is small enough for the wavelength to be big enough for direct observation. This is not so in case of large objects. Scientists are trying to make it possible for larger sizes as well.

All this has given you a starting point to understand what quantum physics is. As you read on, you will learn much more about how it originated and what it entails. Quantum mechanics have a huge scope for improving on a number of things more than classical physics.

The Three Revolutionary Principles of Quantum Physics

Over many decades, there was a lot that the math of classical mechanics could not explain. This was where quantum mechanics came into the picture. Quantum mechanics uses many mathematical concepts to explain such experiments. There is no single scientist who came up with quantum physics; many together contributed to its development and their theories only began getting acceptance around the early 1900's. There were three particularly revolutionary principles that laid its foundation in the scientific world.

Quantized Properties

Certain properties like color and speed are only supposed to occur in set spaces the same way a dial clicks on one number at a time. This challenges a fundamental assumption from classical physics that states that such properties should be on a smooth continuous spectrum. In order to explain that certain properties "clicked" a certain way, the term "quantized" was coined.

Wave-Particle Duality

Particles of light – Initially, the statement that light could sometimes behave like particles was harshly criticized. This was because for nearly 200 years, all experiments were based on and proved that light behaved in the form of a wave. Light could bounce off walls or bend around corners and have crests and troughs like those of an ocean wave. The source of light is like an object that is rhythmically dipped in the center of water. The color then emitted will correspond to the distance between crests that is determined by the ball's rhythmic speed.

Waves of matter – Matter was believed to only exist as particles. This was what decades of experiments had proven. It was then shown that matter could also behave like a wave.

The Uncertainty Principle

The uncertainty principle plays another major role in the development of quantum physics. In 1927, Heisenberg reasoned that there is a limit to how much precision of each property can be known. This is because since matter can act as waves, properties like the position and speed of an electron are complementary and there is a limit to determining the precision. According to him, the more precise the location, the less precise the speed of the electron is to be known. This also applies vice versa. It applies to everyday objects as well; the lack of precision is extremely tiny and is thus not noticeable.

These differentiate quantum physics from classical physics. So, let us look into it further in the text.

Chapter Two: History of Quantum Physics

Even as far back as 500 BC we see that Ancient Greek Philosophers speculated about the smallest part of a material or if matter can be divided at infinite. Around the late 1800's chemistry and the Brownian motion principle were used to answer such questions. Initially scientists defined the atom as the smallest particle of matter. Then there were studies on how atoms themselves were construed and what they were made of. It took more time to discover that atoms were made of protons and neutrons and that their own properties were different from that of the atom itself. And then later that quarks and gluons made them. The development of quantum physics was actually based on creating a viable model to study and explain the structure of atoms more minutely. When we study most theories, we see that classical theories tend to be insufficient or break down if we proceed towards a realm that is remote from normal experience. We see that classical Newtonian physics fail when we consider systems that travel too fast or it is about strong gravity, etc. It doesn't apply when instead of macroscopic objects we consider the microscopic world or even further in.

Around the 17th and 18th century, there was a lot of scientific inquiry about the wave nature of light. Scientists such as Robert Hooke, Leonhard Euler, and Christian Huygens had used experimental observations to propose a wave theory of light. The famous double-slit experiment performed by Thomas Young in 1803 also played a major role in people accepting this wave theory of light. Then Michael Faraday, in 1838, discovered cathode rays. After this Gustav Kirchkoff stated the blackbody radiation problem in 1859. In 1877 Ludwig Boltzmann suggested that a physical system can have discrete energy states and Max Planck gave his quantum hypothesis in 1900. One thing led to another and helped all this make sense altogether. The patterns observed in the observations of blackbody radiation were matching with what Planck hypothesized.

In 1896, its namesake Wilhelm Wien determined “Wien’s law”. The law determined the distribution of blackbody radiation. Using Maxwell’s equations, Ludwig Boltzmann also reached this result independently. This underestimated radiance at low frequency and was valid just for high-frequencies. Planck who used Boltzmann’s statistics and proposed “Planck’s Law” later corrected the model. This Planck’s law played a major contribution to quantum physics.

Some of the first few scientists who studied quantum phenomena were Pieter Zeeman, C.V. Raman, and Arthur Compton. Some prominent quantum effects are named after these brilliant minds. Robert Andrews Millikan experimentally studied the photoelectric effect, but Albert Einstein developed the theory. Similarly, Neils Bohr developed the theory of atomic structure though Ernest Rutherford’s experiments discovered the actual structure of an atom. This theory was extended by Peter Debye to include elliptical orbits. This phase is referred to as the old quantum theory.

The Quantum theory was developed as different scientists made a series of discoveries or logical guesses. All these were sown together to create the theory of quantum physics. Some of the major steps towards it were:

- Max Planck’s Black Body Theory in 1900
- Einstein’s Light Quanta in 1905
- Bohr’s Model of the Hydrogen Atom in 1913
- De Broglie’s Hypothesis in 1924

These four contributions played a major role in advancing the field of physics in the world and, more particularly, the field of quantum physics. Let us look at some of the developments that led to the growth of this field separately from classical physics.

1. Thomas Young carried out the double-slit experiment to show the wave nature of light in 1801.
2. In 1896 Henri Becquerel discovered radioactivity.
3. In 1897, J.J. Thompson discovered the electron and its negative charge with his cathode ray tube experiments.
4. Ludwig Boltzmann was the founder of the Austrian Mathematical Society. In 1877 he suggested that the energy levels of a physical system like a molecule could be discrete. He founded this based on his studies in statistical mechanics and statistical thermodynamics and backed it with mathematical arguments.
5. Max Planck, a German physicist, introduced the idea of energy being "quantized", in 1900. This was reluctantly done in his attempt to derive Planck's Law, as it is still known. This formula was created for the frequency dependence of energy that is emitted by black bodies. The Wien approximation from earlier can be derived from Planck's law as well.
6. Planck's quantum theory helped Stefan Procopius and Neils Bohr in calculating the magnetic moment of electrons. This was later called the magneton. It was also possible to make similar computations of the magnetic moments of protons and neutrons.
7. Einstein then explained the photoelectric effect in 1905 by postulating that all electromagnetic radiation including light could be divided into a number in energy quanta, which were localized points in space.
8. In 1909, Robert Millikan showed that electric charge

occurs as quanta with his oil drop experiment.

9. In 1911 the planetary model of the atom was developed when Ernest Rutherford showed that the plum pudding model of atom was invalid.

10. The Bohr used quantization to explain the spectral lines of hydrogen atoms in 1913.

11. In 1912, Henri Poincare thoroughly discussed Planck's theory in this paper "Sur la theorie des quanta".

12. All these together are referred to as the old quantum theory.

13. Louis De Broglie was a French Physicist who put forward another theory in 1923. He suggested that particles could have wave characteristics and waves could have particle characteristics. He developed this theory from that of special relativity and applied it to a single particle.

14. Modern quantum physics was born when physicists Werner Heisenberg, Pascual Jordan and Max Born used De Broglie's approach to develop matrix mechanic in 1925.

15. Simultaneously, Erwin Schrodinger invented the wave equation and Schrodinger equation. He also put forward the thinking experiment that everyone knows as Schrodinger's cat.

16. In 1927, Heisenberg put forward the uncertainty principle.

17. The Copenhagen interpretation was also taking shape around the same time. You will read more about this further in the book.

18. Paul Dirac started working on unifying special relativity with quantum mechanics. He proposed the Dirac equation for electrons. This equation did one up on Schrodinger equation by being able to achieve the relativistic

description of an electron's wave function. The Dirac equation also predicts electron spin and he predicted the existence of Positrons. Dirac also established the use of the operator theory.

19. John Von Neumann was a Hungarian Polymath who formulated an arduous mathematical base for quantum physics. In his book published in 1932, he published the theory of linear operators on Hilbert spaces. This work is still valid.

20. Quantum field theories started developing when scientists began applying the quantum mechanics to fields and not just singular particles. P.A.M. Dirac and P. Jordan are some of the contributors in this part. This research helped the formulation for quantum electrodynamics in the 1940s by F. Dyson, R.P. Feynman, S. Tomonaga, and J. Schwinger. Quantum electrodynamics served as a model for quantum field theories later on. It described a quantum theory involving electrons, positrons and electromagnetic fields.

21. In 1955, Clyde L. Cowan and Frederick Reines verified the existence of neutrinos.

22. In the 1960s the theory for quantum chromodynamics started being formulated. The present-day theory was refined in 1975 by Gross, Politzer, and Wilczek.

23. Glashow, Salam, and Weinberg received the Nobel Prize in 1979 for physics when they showed a single electroweak force would be obtained if a weak nuclear force were merged with quantum electrodynamics. This work was built on the pioneering research of Higgs, Schwinger, and Goldstone.

As you can see, science is a field that continually redefines things that we were previously sure or unsure of. The field of quantum physics was established based on this. The works of decades by many scientists has given us the knowledge of the atomic and subatomic world that we now have. This field is still in a stage of infancy and has a long way to go before we know more in detail and with perfect accuracy.

Chapter Three: Theories of Matter

Matter was known to be in two forms at the end of the nineteenth century; one was particle and the other form was waves.

Particles were like a localized mass that flew around like tiny bullets. Out of all fundamental particles, electrons were the most investigated. In 1896, Thompson conducted his cathode ray tube experiment. He found that the cathode rays in cathode ray tubes were deflected by magnetic and electric fields, like tiny bits of matter charged with electricity. Atoms were also particulate in matter.

The other form was matter in waveform. The most properly investigated of these was light or electromagnetic waves. Many scientists in the seventeenth century gave accounts of how light consisted of a shower of tiny little corpuscles. Newton's corpuscular view remained dominant at the time even though some had suggested the account of wave-like behavior. This only changed at the beginning of the nineteenth century when those like Thomas Young drew different inferences from their studies.

The two-slit experiment is the most recognized interference effect. In this experiment, waves of light strike a barrier that has two holes in it. The waves are shown as parallel wave fronts that move up the screen. From the two slits, secondary waves will radiate out and interfere with one another. This forms the cross-hatching pattern of interference that is characteristic. The same patterns can be observed on the surface of a pond when pebbles are dropped in the water and ripples are caused. These ripples will have the same pattern observed here. The manner in which the waves combine is of importance in this kind of interference experiment. It is because waves may add up to two ways that these patterns will arise.

The phases of waves in constructive interference will add to form combined waves of greater amplitude. Every part of each wave will line up to interfere constructively in every place. Destructive interference causes the phases to occur in a way that they subtract to cancel out. Every part of the waves will line up in a manner that they interfere destructively in every part.

Ordinary cases of interference like the two-slit experiment exhibits both constructive and destructive interference in different parts where intersection of the waves happen. Complicated interference patterns will be observed in such cases. If you think of waves as a kind of displacement in mediums, they can be easily understood. For instance, in the ocean a wave will have peaks where the water is above sea level and troughs where the water is below sea level. When two waves meet and if their peaks coincide, a peak with combined height will result from these. This can be understood as constructive interference. If the peak of a wave coincides with the trough of another, the two will cancel each other out. This pattern is called destructive interference.

The explanation of interference was very compelling for Maxwell. He considered it good evidence in case of ether. According to him, light had to be a displacement in something in order for it to have peaks and troughs that can be cancelled out. That carrier could be ether. He surmised that if light was made up of many tiny corpuscles, then it might be impossible to combine two and cause self-annihilation. The ether theory died out but there was a possibility for something better. Somehow, light came in a form that could cancel out other light waves. This was an early indication for the later deductions of quantum theory.

All of this was at the end of the nineteenth century and formed the foundation for more.

The quantum theory of matter is a microscopic explanation of