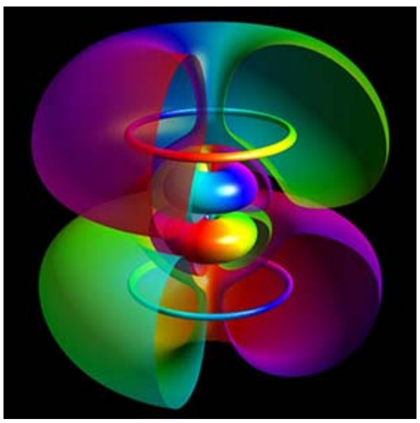
The Difficulty with Quantum Mechanics

Saad Zaheer

I was walking down the Infinite Corridor, the iconic hallway of the MIT campus, when I came across Professor Wit Busza, who was my lecturer during my freshman year at MIT in a course on waves and oscillations. He was quite delighted to learn that I was already halfway through my undergraduate career. After inquiring about his health and research, I was keen to tell him that I had completed the undergraduate sequence on Quantum Mechanics and had had the most fun time doing it. He smiled back and said, "If you ever think you've understood quantum mechanics, come back and teach me. I still don't get it."

Professor Busza is a very senior and accomplished particle physicist and a student of Richard Feynman. A couple of years back, I would have been shocked at his comment, but now, it seemed perfectly reasonable. I must clarify here that I take a very strong exception to comments made about how difficult or conceptually involved anything is; over the past two years I have come to believe that most science concepts assumed to be entirely inaccessible to normal folks are thought to be so either due to inefficient teaching or wrong analogies. Obviously, this was not the first time I had heard such a thing; such remarks about Quantum Mechanics have been fairly common in Physics circles and have also become rather fashionable in science fiction books and magazines. But why does everyone really think so? Truth be told, once the legitimacy of the theory is recognized, the techniques and principles one needs to apply in quantum mechanics to solve problems are fairly straightforward. What, then, is really the mystery about this theory?

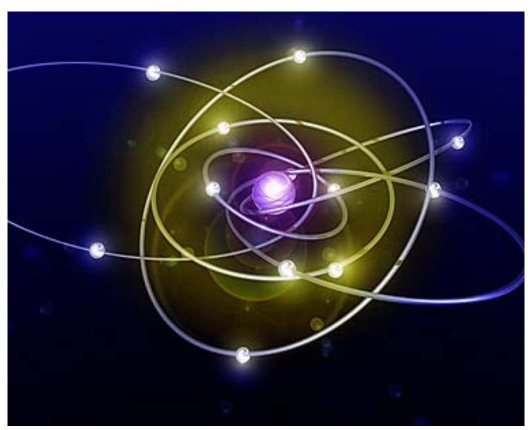


The difficulty with Quantum Mechanics is not computational; such issues are least worrisome to a theorist. On the contrary, the difficulty is merely philosophical and that of interpretation. The answer lies in the realization that unlike other physical theories, quantum mechanics is a compromise of sorts with nature. Its justification as the most plausible description of nature is neither the result of a thought experiment nor the logical consequence of some intuition. It has been, in fact, developed on the basis of numerous attempts to explain some very shocking experimental results from the beginning of the 20th century. As more and more unexplainable facts piled up, it became harder and harder to reconcile them with our classical understanding of nature and we had to look for alternative answers. The answer which physicists came up with had little in common with what makes sense to ordinary human beings, which is why it was hard to make analogies and reason logically towards a general understanding of the theory (the fact that the theory is quite complicated didn't make things any easier). It is this philosophical difficulty that makes quantum mechanics so hard to comprehend.

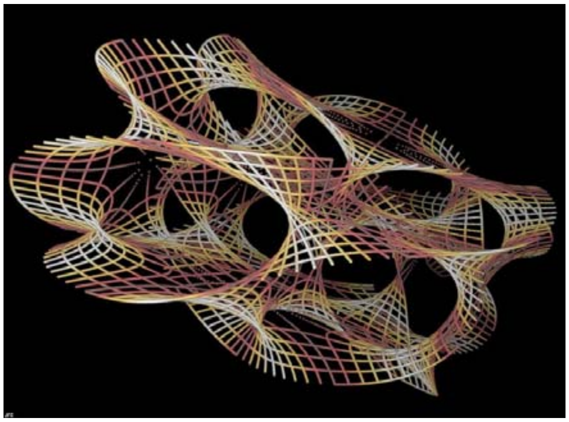
Any theory that views the world as being completely deterministic falls under the category of classics. Classical theories like Newton's Mechanics or Einstein's General Relativity ask for the most complete description of the dynamics of bodies. They venture to determine, to pinpoint accuracy, the positions and orientations of bodies at all times in space. Of course, the complexity and variety of phenomenon occurring simultaneously in a subset of space make computing these positions and orientations extremely non-trivial in most cases, but such mathematical complications can be overcome given sufficient computational tools. Research in classical fields centers around two points. First, the determination of a plausible framework to interpret events logically and sensibly. Newton's Mechanics and Einstein's General Relativity are the more famous examples of this, owing to their successes, but there have definitely been others that were replaced or merged into the broader framework of the above theories. Secondly, and, in a way, more importantly, is the expansion of the conceptual framework of *the theory* by its application to some unrelated real world phenomena and conjecturing about the outcomes. An experiment puts these conjectures to test and acts as an impartial judge to determine the validity and generalizability of the theory.

Things were alright for Newton's Mechanics until some experiments were performed to study the inside of the atom and to map the radiation out of the so-called black bodies, which in principle radiate only because of their heat content. There were also some other bizarre facts like the allotropic forms of hydrogen and the confusion with regards to the status of light as a particle or a wave. It will be irrelevant to discuss the whys and the hows behind such experiments but it is sufficient to know that they highlighted the incompleteness of Newton's theory towards offering reasonable insights into their outcomes. I always used to wonder why it took so many people and so many years to formulate quantum mechanics. I have now come to understand that it could not have been otherwise. One shy deviation from the principles of Newtonian Mechanics to explain a confounding experimental result proved to be wrong in some other subtle way, and so it took many trial assumptions and ideas from various people over many years to concur upon a central set of principles that brought forth a coherent perspective on events and outcomes as observed experimentally. Now these ideas were not merely mental exercises, they were more like ways to get to a known answer through the most plausible explanation. It took this much time because the larger the number of deviations from the classical theory there were, the harder it became to put them all in one framework. Fast forward thirty to forty years and out pops Quantum Mechanics. The result: we are still wondering how bizarrely nature behaves the way it does I remember telling a friend once that a human being could possibly never come up with such a theory in his head, no matter what.

I should emphasize here the word *human*. If there is one way in which nature sets a scale that is eternally absolute and not relative, it is in terms of size. The phenomena we are exposed to as human beings and which have been imprinted into our genetic heritage incline us to think only in a very deterministic way. We always see things standing at a point if nothing moves them, we always notice an instantaneous cause and effect pattern in events and expect such patterns to persist at all scales of size. But, at the atomic and subatomic scale things do not act like they do when they are our size. It is mainly because these things are not things in the sense in which we understand them to be. They act material only when we treat them like a material but they act like a transparent beam or ray of light when treated like a beam of light. Then what are these things? We say they are light-like waves and particles simultaneously, both at the same time. And then their light-like nature has other bizarre consequences. A wave is something that oscillates in time and in space which causes it to move in a certain direction. The number of repetitions of a wave in a certain amount of time, lets say a second, is called frequency. Similarly, such repetitions in space in intervals of space, say a meter long, are called wave numbers or space frequency. We can find the frequency by measuring the repetitions of these oscillations in space or time and in fact use these numbers to measure intervals of time and space. But, what if there is a certain event that spans an interval of time smaller than the time it takes the wave to complete a single oscillation? We cannot measure such intervals very precisely but only approximately. So, when we assign a wave-like status to objects at the atomic scale, we have to live with this certain uncertainty in our ability to measure time and space intervals simultaneously. This is the foundation of the Heisenberg's Uncertainty Principle and has been the basis of much mystery and furor behind Quantum Mechanics.



My purpose was not to explain or state the Uncertainty Principle, but to illustrate a point. The whole uncertainty issue came in when we started thinking of objects as waves, which, ironically, couldn't be avoided given the considerable experimental evidence in favor of the waves. In other words, we had to make a compromise because there was no way out. On the face of it, the wave business seems pretty ridiculous but developing it further shows that it only *looks* flawed but is in fact not so. The evident and not so evident consequences of this one principle gave rise to other new ideas leading to better and more elegant descriptions which people have been working on for the last eighty or so years. For the curious reader, this is not the whole story. It was later discovered that the particle or matter-like nature of objects at the atomic scale is actually just a wave oscillating in a certain way and the more fundamental entity is neither the wave nor the particle, but something called a *field* that looks like a three dimensional piano string tied on both ends, which happen to be at infinity, that oscillates and curves in arbitrary ways. Each way in which it oscillates and curves is a different particle which happens to be one of the elementary building blocks of matter (e.g. electrons, photons, quarks and neutrinos). And all this is only a rudimentary introduction to the complex world of quantum mechanics.



In my personal opinion, the difficulty behind quantum mechanics is one of principles and not of a lack of physical insight. Perhaps it is not possible for us to ever come to terms with this theory.

(Saad Zaheer is pursing his undergraduate degree in Physics at the Massachusetts Institute of Technology. He was a participant of NPTC-8 and represented Pakistan in the International Physics Olympiad at Pohang, South Korea in 2004. He is currently researching on the Casimir Effect under the supervision of Professor Robert Jaffe of MIT. Previously, he has worked at the MIT Laser Interferometer Gravitational Waves Observatory building low mass mirror interferometers)