Part 1 - The Double-Slit Experiment: A Classic Example of Quantum Weirdness

Author: Jim Adson10/19/2002, This article is also available online at Physics Post:
http://www.physicspost.com/science-article-10.html
Also quoted, experts from http://www.thekeyboard.org.uk/Quantum%20mechanics.htm by Keith Mayes

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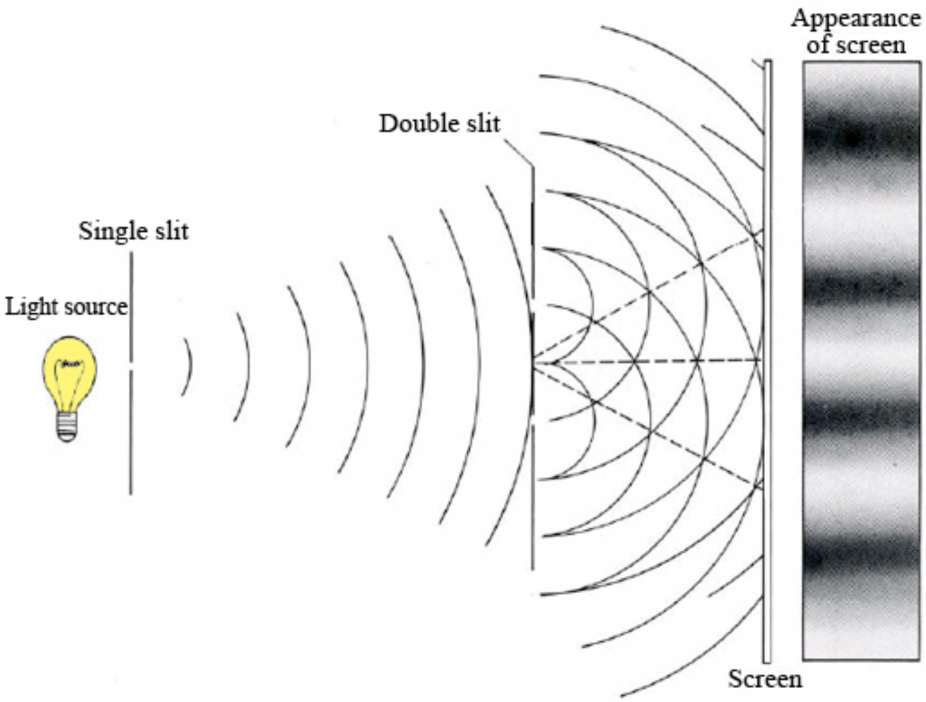
It helps to watch an animated version of this experiment, go to this link:

http://www.youtube.com/watch?v=DfPeprQ7oGc
or
go to the our class Raku wordpress site, it is embedded under *Links to internet material:*, #5

"Quantum theory is bizarre. In order to try and understand it we need to forget everything we know about cause and effect, reality, certainty, and much else besides. This is a different world; it has its own rules, rules of probability that make no sense in our everyday world. Richard Feynman, the greatest physicist of his generation, said of quantum theory 'It is impossible, absolutely impossible to explain it in any classical way'. Quantum theory is much more than just bizarre; it is also without doubt the most amazing theory inexistence . . .. This theory is not just about experiments and equations, it reveals something extraordinary about our very understanding of what constitutes reality.

Although there are many wonderful examples of the strangeness of Quantum Mechanics, few more clearly illustrate the effect of the observer on the outcome of the experiment than this. Quantum theory however, needs some introduction before we get too involved in the experiment. The standard explanation of what takes place at the quantum level is known as the Copenhagen Interpretation. This is because much of the pioneering work was carried out by the Danish physicist Niels Bohr, who worked in Copenhagen. Quantum theory attempts to describe the behavior of very small objects, generally speaking the size of atoms or smaller, in much the same way as relativity describes the laws of larger everyday objects. We find it necessary to have two sets of rules because particles do not behave in the same way as larger everyday objects, such as billiard balls. We can, for example, say precisely where a billiard ball is, what it is doing, and what it is about to do. The same cannot be said for particles. They are, quite literally, a law unto themselves, and why this should be so is a source of much debate. The classic experiment to illustrate this is the famous double slit experiment, originally devised to determine if light travels as waves or particles. – Keith Mayes"



The Experiment

The experimental setup is very simple. Start out with a light source. Any source will do, although a laser is the common choice because it has uniform wavelength. Some distance from the light source, there is a screen. It can be a white surface, or a piece of photographic film. Between the screen and the light source is a plate with two narrow slits cut in it. The light from the light source passes through the slits and lands on the screen. The light on the screen will form a specific pattern depending on how the experiment is set up.

"If light travels as particles we can imagine particles of light (photons) as bullets fired from a rifle. Imagine a brick wall with two holes in it, each the same size and large enough to fire bullets through, with a second wall behind where the bullets will strike. After firing a few rounds you would expect to see on the second wall two clusters of hits in line with the two holes. This is of course precisely what you get with bullets, so if we get the same result with photons we can say they are particles. Now imagine that instead of particles, that light travels as a wave, we can replicate that with a water tank. As the wave spreads out from its source it would reach both holes at the same time and each hole would then act as a new source. Waves would then spread out again from each of the holes, exactly in step, or in phase, and as the waves moved forward, spreading as they go, they would eventually interfere with one another. Waves that meet peak-to-peak or trough-to-trough will amplify each other, and waves that meet peak-to-trough will cancel each other out. The interference pattern of light waves looks like a series of bright and dark bands that stretch across the screen, with the brightest band directly between the two slits.

If we carried out this procedure with light instead of water, and if light travels as waves, then the pattern on the second wall would appear as an interference pattern of alternate dark and light bands across the wall. Particles, on the other hand, would produce two separate areas of light (where the bullets would hit). This experiment has in fact been carried out many, many times, with the same results every time, and the results are nothing less than amazing. No matter which one of the slits you cover, as long as there is only one opening for the light to go through. This brings us to the all-important question; if light is a particle, why does it form an interference pattern?

Quantum Weirdness

One difference between the experiment with photons and the experiment with bullets is that only one bullet at a time is going through the apparatus, where trillions of photons go through the apparatus at a time. The interference could be caused by the photons bouncing off each other. This seems to make a fair amount of sense unless you allow only one particle at a time to go through the apparatus. Replace the light source with a device that emits a single photon at a time. Intuitively, you would expect the photon to leave the device, travel through one of the two slits, and land on the screen. If this is what happens, you should not see an interference pattern because there is nothing for that solitary photon to interfere with. But that is not what happens. If one photon is fired through the experiment at a time, an interference pattern will build up gradually. It doesn't matter how long of an interval there is between the photons, as long as only one is permitted to be in the experiment at a time. The photon interferes with itself, meaning the single photon goes through both holes at once.

"We could try peeking, to see which hole the photon goes through, and to see if it goes through both holes at once, or if half a photon goes through each hole. When the experiment is carried out, and detectors are placed at the holes to record the passage of electrons through each of the holes, the result is even more bizarre. Imagine an arrangement that records which hole a photon goes through but lets it pass on its way to the detector screen. Now the photons behave like normal, self-respecting everyday particles. We always see a photon at one hole or the other, never both at once, and now the pattern that builds up on the detector screen is exactly equivalent to the pattern for bullets, with no trace of interference. As if that was not bad enough, it gets even worse! We do not need to place detectors at both holes; we can get the same result by watching just one hole. If a photon passes through a hole that does not have a detector, it not only knows if the other hole is open or not, it knows if the other hole is being observed! If there is no detector at the other hole as well as the one it is passing through, it will produce an interference pattern; otherwise it will act as a particle. When we are watching the holes we can't catch out the photon going through both at once, it will only go through one. When we are not watching it will go through both at the same time! There is no clearer example of the interaction of the observer with the experiment. When we try to look at the spread-out photon wave, it collapses into a definite particle, but when we are not looking it keeps its options open. What the double slit experiment demonstrates is this: Each photon starts out as a single photon - a particle -and arrives at the detector as a particle, but appears to have gone through both holes at once, interfered with itself, and worked out just where to place itself on the detector to make its own small contribution to the overall interference pattern. This behavior raises a number of significant problems! Does the photon go through both holes at the same time? How does a photon go through both holes at the same time? How does it know where to place itself on the detector to form part of the overall pattern? Why don't all the photons follow the same path and end up in the same place?" Keith Mayes

Down the Rabbit Hole

"The double slit experiment is not simply an oddball theory that has no application in the real world. This strange behavior of particles lies at the very heart of our understanding of the physical properties of the world. Quantum theory is used in many applications, including television and computers, and even explains the nuclear processes taking place inside stars. One possible explanation for quantum weirdness is a theory concerning the nature of the wave that is passing through the experiment. The key concept of the theory, which forms a central part of the Copenhagen Interpretation, is known as the 'collapse of the wave function'. The theory seeks to explain how an entity such as a photon or an electron, could 'travel as a wave but arrive as a particle'. According to the theory, what is passing through the experiment is not a material wave at all, but is a 'probability wave'. In other words, the particle does not have a definite location, but has a probability of being here or there, or somewhere else entirely. Some locations will be more probable than others, such as the light areas in the interference pattern for example, and some will be less probable, such as in the dark areas. In this theory, an electron that is not being observed does not exist as a particle at all, but has a wave-like property covering the areas of probability where it could be found. Once the electron is observed, the wave function collapses and the electron becomes a particle. This theory rather neatly explains the behavior of the particles in the double slit experiment. When we are not looking at the particle, the probability wave, of even a single particle, is spread out and will pass through both slits at the same time and arrive at the detector as a wave showing an interference pattern. When we observe the electron by placing detectors at the slits, it is forced into revealing its location which causes the probability wave to collapse into a particle. If the theory is correct, its implications are staggering. What it suggests is that nothing is real until it has been observed! Nothing is real until it has been observed! This clearly needs thinking about. Are we really saying that in the 'real' world - outside of the laboratory - that until a thing has been observed it doesn't exist? This is precisely what the Copenhagen Interpretation is telling us about reality. This has caused some very well respected cosmologists (Stephen Hawking for one) to worry that this implies that there must actually be something 'outside' the universe to look at the universe as a whole and collapse its overall wave function. John Wheeler puts forward an argument that it is only the presence of conscious observers, in the form of ourselves, that has collapsed the wave function and made the universe exist. If we take this to be true, then the universe only exists because we are looking at it." Keith Mayes

The double-slit experiment was originally devised to prove that light was a wave. Later versions in which only one particle at a time could travel through the experiment were devised as a thought experiment to illustrate the absurdity of Quantum Mechanics. Due to the extreme technical difficulties involved in such an experiment, many expected it to remain an odd product of theory. In the late 1980s, a group in Paris managed to carry out this experiment, and it agreed completely with theory. It is important to remember that these experiments have been carried out, and our universe is every bit as strange as quantum theory suggests.

postscript

Recent studies, reported in a 2003 article, have revealed that interference is not restricted solely to elementary particles such as protons, neutrons, and electrons. Specifically, it has been shown that large molecular structures like fullerene (C_{60}) also produce interference patterns.[28]

Part 2 - Fritjof Capra, The Tao of Physics, 1975
(excerpts & Quotes)

The following excerpts from *The Tao of Physics* summarizes Capra's motivation for writing this book as well as exploring the connection between modern physics (quantum theory) and Eastern mysticism / philosophy. “Physicists do not need mysticism, and mystics do not need physics, but humanity needs both.” – (epilogue)

The book grew out of an inspirational moment Capra had. . . later he discussed his ideas with Werner Heisenberg in 1972, as he mentioned in the following interview excerpt: I had several discussions with Heisenberg. I lived in England then [circa 1972], and I visited him several times in Munich and showed him the whole manuscript chapter by chapter. He was very interested and very open, and he told me something that I think is not known publicly because he never published it. He said that he was well aware of these parallels. While he was working on quantum theory he went to India to lecture and was a guest of Tagore. He talked a lot with Tagore about Indian philosophy. Heisenberg told me that these talks had helped him a lot with his work in physics, because they showed him that all these new ideas in quantum physics were in fact not all that crazy. He realized there was, in fact, a whole culture that subscribed to very similar ideas. Heisenberg said that this was a great help for him. Niels Bohr had a similar experience when he went to China. – Fritjof Capra, interviewed by Renee Weber in the book *The Holographic Paradigm* (page 217–218). As a result of those influences, Bohr adopted the yin yang symbol as part of his family coat of arms when he was knighted in 1947. *The Tao of Physics* was followed by other books of the same genre like *The Hidden Connection*, *The Turning Point* and *The Web of Life* in which Capra extended the argument of how Eastern mysticism and scientific findings of today relate, and how Eastern mysticism might also have answers to some of the biggest scientific challenges of today.

“The purpose of this book (the Tao of Physics) is to explore the relationship between the concepts of modern physics and the basic ideas in the philosophical and religious traditions of the Far East. We shall see how the two foundations of twentieth-century physics - quantum theory and relativity - both force us to see the world very much in the way a Hindu, Buddhist or Taoist sees it ..”

The most important characteristic of the Eastern worldview - one could almost say the essence of it- is the awareness of the unity and mutual interrelation of all things and events, the experience of all phenomena in the world as manifestations of a basic oneness. All things are seen as interdependent and inseparable parts of this cosmic whole; as different manifestations of the same ultimate reality. “
“The Eastern mystics see the universe as an inseparable web, whose interconnections are dynamic and not static. The cosmic web is alive; it moves and grows and changes continually. Modern physics, too, has come to conceive of the universe as such a web of relations and, like Eastern mysticism, has recognized that this web is intrinsically dynamic. The dynamic aspect of matter arises in quantum theory as a consequence of the wave-nature of subatomic particles, and is even more essential in relativity theory, where the unification of space and time implies that the being of matter cannot be separated from its activity. The properties of subatomic particles can therefore only be understood in a dynamic context; in terms of movement, interaction and transformation.“

Fritjof Capra is correct that matter cannot be separated from activity; the error of modern physics has been in the conception of Motion as the motion of Matter ('subatomic particles') rather than the wave motion of Space. Western Physics (with its 'particles' and 'forces / fields' in 'Space Time’) has never correctly understood the Eastern worldview. It is also important to understand that the ancient Indian philosophers did not actually know how the universe was a dynamic unity, what matter was, how the One Thing / Brahman caused and connected the many things. Thus Eastern philosophical knowledge is ultimately founded on mysticism and intuition.

A careful analysis of the process of observation in atomic physics has shown that the subatomic particles have no meaning as isolated entities, but can only be understood as interconnections between the preparation of an experiment and the subsequent measurement. Quantum theory thus reveals a basic oneness of the universe. The mathematical framework of quantum theory has passed countless successful tests and is now universally accepted as a consistent and accurate description of all atomic phenomena. The verbal interpretation, on the other hand, i.e. the metaphysics of quantum theory, is on far less solid ground. In fact, in more than forty years physicists have not been able to provide a clear metaphysical model. (Capra, 1975)

The Metaphysics of Space and Motion and the Wave Structure of Matter now provides this 'clear metaphysical model'. A significant problem has been the conception of the 'particle' and thus the resulting paradox of the 'particle / wave' duality. These problems have caused great confusion within modern physics over the past seventy years, as Heisenberg, Davies and Capra explain;

Both matter and radiation possess a remarkable duality of character, as they sometimes exhibit the properties of waves, at other times those of particles. Now it is obvious that a thing cannot be a form of wave motion and composed of particles at the same time - the two concepts are too different. (Heisenberg, 1930)

The idea that something can be both a wave and a particle defies imagination, but the existence of this wave-particle "duality" is not in doubt. .. It is impossible to visualize a wave-particle, so don't try. ... The notion of a particle being "everywhere at once" is impossible to imagine. (Davies, 1985)

The problems of language here are really serious. We wish to speak in some way about the structure of the atoms … But we cannot speak about atoms in ordinary language. (Heisenberg, The Tao of Physics, p53)

That every word or concept, clear as it may seem to be, has only a limited range of applicability. (Heisenberg, The Tao of Physics, p35)

The most difficult problem … concerning the use of the language arises in quantum theory. Here we have at first no simple guide for correlating the mathematical symbols with concepts of ordinary language: and the only thing we know from the start is the fact that our common concepts cannot be applied to the structure of the atoms. (Heisenberg, The Tao of Physics, p54)

The 'this' is also 'that'. The 'that' is also 'this'… That the that and the this cease to be opposites is the very essence of the Tao. Only this essence, an axis as it were, is the center of the circle responding to endless changes. (Quoted in Fung Yu-Ling, A Short History of Chinese Philosophy, 1958 p.112)

The opening line of the Tao Te Ching: 'The Tao that can be expressed is not the eternal Tao.' Lao Tzu
Well known Zen phrase: "The instant you speak about a thing you miss the mark."

The apparent contradiction between the particle and the wave picture was solved in a completely unexpected way which called in question the very foundation of the mechanistic world view - the concept of the reality of matter. At the sub-atomic level, matter does not exist with certainty at definite places, but rather shows 'tendencies to exist' and atomic events do not occur with certainty at definite times and in definite ways, but rather show 'tendencies to occur'. In the formalism of quantum theory, these tendencies are expressed as probabilities and are associated with mathematical quantities which take the form of waves. This is why particles can be waves at the same time. They are not 'real' three-dimensional waves like sound or water waves. They are 'probability waves', abstract mathematical quantities with all the characteristic properties of waves which are related to the probabilities of finding the particles at particular points in space and at particular times. (Fritjof Capra, The Tao of Physics, p78)