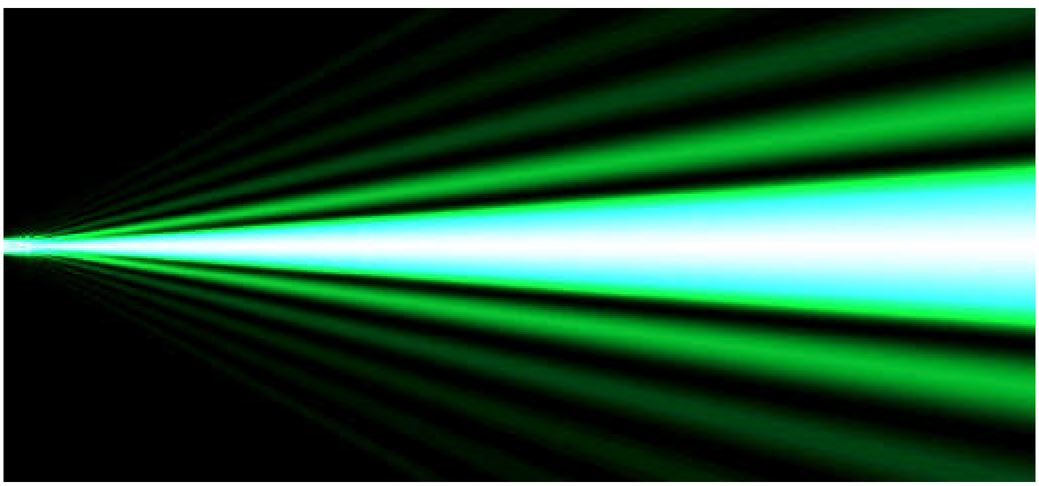
The Many-Worlds Interpretation of Quantum Mechanics

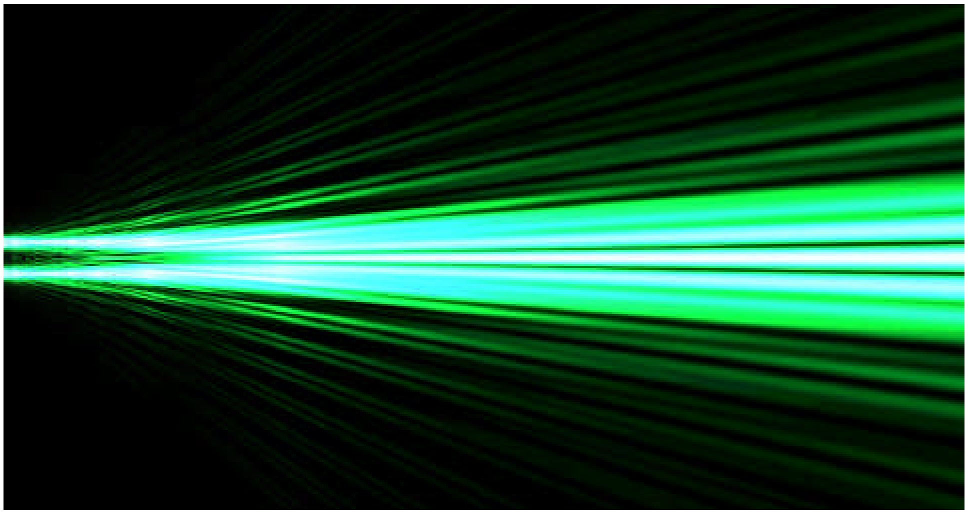
Cameo Wood - cwood@bennington.edu
Professor Derby - Spacetime Physics

The beginning of the idea of the Many Worlds Interpretation began with Everett's Relative-State Formulation of Quantum Mechanics. While at Princeton University as a Graduate student studying with Wheeler, he formulated his interpretation as his dissertation. This paper explores the idea of a series of worlds occupying the same space but an added dimension of probability. Everett, and later scientists like DeWitt and Deutsch, believed that there is a splitting of worlds whenever there is any non-zero probability on a quantum level. Each possible outcome manifests itself into a strand of time and space, and then continues to split upon every non-zero probability. This theory inspires amazement and annoyance in armchair physics enthusiasts as well as scientists. For others, it offers a new and challenging way of conceiving our world and what an added dimension could be like.

The English scientist Thomas Young performed a now classical quantum optics experiment in 1801 that demonstrated the wave nature of light by showing that two overlapping light waves interfered with each other. This experiment was important because he was able to calculate the wavelength of light from the measurements from this experiment, which at the time was an important discovery. This experiment was also revolutionary because it explored for the first time the wave-particle duality of light. Young set up a torch with which light would be directed through two slits and then a pattern would be produced on a surface after a small distance through the slits. The results were unexpected as bands of darkness and light were produced. It was expected that when two lights were shown next to one another upon one point, that the light would be doubly strong, and nor blacked out completely as a result.



This effect, called interference or a "fringe pattern" is only seen in this type of experiment, or at the quantum level, and is not seen in normal life. While interference between waves can be understood with water in a small wave pool, and seeing how two separate sources could interfere with one another's waves, the results grew more complicated as more experiments were conducted.



In 1923 a graduate student named Louis de Broglie questioned that if light waves could exhibit particle-like behaviour, could particles exhibit wave-like behaviour. He conducted experiments to find wavelengths of different kinds of matter, like the neutron diffraction pattern and the X-ray diffraction pattern caused by a crystal of rock sale (NaCl). One of the current experiments in quantum optics is to use a red He-Ne laser with a photon tube, and to capture the images of the photon pattern and interference with a CCD camera and a frame grabber. As the frames progress they show an accumulation of spots in time. As the electrons continue to strike the CCD, they again accumulate in the fringe pattern. Bright areas occur where there is a high probability of electrons striking the CCD, and where there is darkness indicates a low probability. After this experiment, de Brolie discovered that this was the key to understanding particle waves. He found that particle waves are waves of probability, where the accumulation of electrons in a particular place can indicate a probability that the particle would be found at that point in space and time

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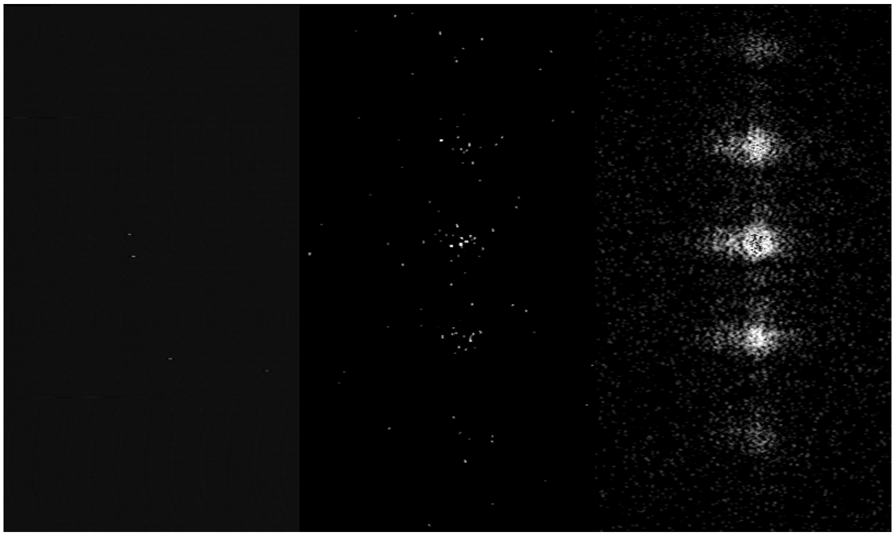

In response to Young and de Broglie's experiments, Everett's paper was an improvable hypothosis using their results in order to solve the problem of collapse of the wave function in quantum mechanics. Since Everett's paper was published in 1957, there has been many mutually incompatable no-collapse theories published that are very different from his original proposal. The two main phenomena that all of these theories are in response to are the von Neumann-Dirac collapse theory and the strange results of Young's double-slit experiment.

Within the MWI, there are two definitions that are critical and peculiar to the MWI itself. There is the definition of "The Universe," in which everything exists, and then, "The World," in which we, as individual entities exist. These semantic differences are critical in understanding the MWI, as there can be many "worlds" within one universe, and that we are not unique in the world and according to the MWI, it is possible for worlds to share identical pasts, but to have completely different futures that are determined by the potential of non-zero probability.

Proponents of the MWI are opposed to the standard theory because of the delineation between the required observers external to the experiment. The MWI theorists argued that this meant that the universe as a whole could never be understood, because the observer must always be external to the universe observed. Therefore, scientists like Everett were concerned that the standard theory could not be used to understand the universe, as the universe contained observers.

The argument then began to erode into semantics and flights of fancy as an Everett understanding of the universe began to be explored. The dynamics of the standard theory versus the relative-state formulation were a conflict over measurement. The standard theory offered two options for the dynamics, one being that if no measurement is made of a quantum physical property, then the system continues to operate on a linear, deterministic Schrödinger dynamic. If a measurement is made, then the quantum property as a system changes to a random state, which may or may not have the property that the observer is measuring.

The standard theory is dependant upon these two dynamical laws in order to account for "collapse dynamics." The first accounts for the randomness that result when a measurement is made, and the other describes what happens when there is no measurement.

Everett was disturbed by the standard theory, as it did not explain how the system could be understood with external observers to the system. He wondered how quantum state changes could be explained without measurements, and how to predict these seemingly random changes. In answer to the standard theory, Everett composed his relative state formulation, which explicitly were included and understood within the framework of wave mechanics. He related these many states to a new theory that could have a no-collapse theory and memory records of both probabilities for one observer.

Everett left his theory very vague, though, and almost all of the various Many-World interpretations reference Everett, even though they are all mutually incompatible. The most popular understanding of Everett is DeWitt's many-worlds interpretation. This theory is useful as a mental exercise of another way of understanding multidimensionality.

> "[Everett's interpretation of quantum mechanics] denies the existence of a separate classical realm and asserts that it makes sense to talk about a state vector for the whole universe. This state vector never collapses and hence reality as a whole is rigorously deterministic. This reality, which is described *jointly* by the dynamical variables and the state vector, is not the reality we customarily think of, but is a reality composed of many worlds. By virtue of the temporal development of the dynamical variables the state vector decomposes naturally into orthogonal vectors, reflecting a continual splitting of the universe into a multitude of mutually unobservable but equally real worlds, in each of which every good measurement has yielded a definite result and in most of which the familiar statistical quantum laws hold." (DeWitt, 1973)

This method of understanding quantum state changes appears to be more elegant and more simple than the Copenhagen view, "If you can't measure it, it doesn't exist." The cost of measuring everything in order to verify its existence on the quantum level is not scalable and not useful. The many-worlds interpretation is a purely conceptual one intended only for visualisation and offers a simple and elegant framework until something yet undiscovered replaces it.

Even for DeWitt, the constant splitting of worlds was a shocking concept, and in his article in 1973, states, "I still recall vividly the shock I experienced on first encountering this multi-world concept. The idea of 10^{100} slightly imperfect copies of oneself all constantly splitting into further copies, which ultimately become unrecognizable, is not easy to reconcile with common sense. Here is schizophrenia with a vengeance." (DeWitt, 1973) DeWitt and perhaps Everett visualised an additional dimension in which superposition and hyperforms could be conceived, where the added dimension is the possibility of all probability, and all worlds coexist in the same space. Even if the interpretation has not a grain of truth in it, it is still an interesting exercise in perceiving ourselves. Another reason to investigate this theory is that it does offer an explanation that includes the observer in any measurement, unlike the Standard Theory, which perhaps is the right direction toward a unified theory. While neither theory is correct, with research and attempts to prove the theories wrong or right, eventually one theory will be proven incorrect, and another theory will take its place.

Bibliography:

Both the single slit and the double slit graphics were acquired from http://www.hotquanta.com/twinslit.html

The CCD photos are from: http://www.physics.brown.edu/Studies/Demo/modern/demo/7a5520.htm

Barrett, Jeffrey A. Everett's Relative-State Formulation of Quantum Mechanics. http://plato.stanford.edu/entries/qm-everett/

Deutsch, David. The Fabric of Reality, Penguin: New York, 1997.

DeWitt, B. S., and N. Graham, eds., 1973, *The Many-Worlds Interpretation of Quantum Mechanics*, (Princeton Univ. Press, Princeton).

Everett, III, H., 1957, Reviews of Modern Physics 29, 454.

Popper, K. R., 1967, in *Quantum Theory and Reality*, ed. M. Bunge, (Springer-Verlag, Berlin).

Wheeler, J. A., 1957, Reviews of Modern Physics 29, 463.

Wheeler, J. A., 1978, in *The Mathematical Foundations of Quantum Mechanics*, ed. A. R. Marlow, (Academic Press, New York).

Wheeler, J. A., and W. H. Zurek, eds., 1983, *Quantum Theory and Measurement*, (Princeton University Press, Princeton, NJ).

Wolf, Fred Alan. Parallel Universes: The Search for Other Worlds, Touchstone: New York, 1988.