# The Many Worlds Interpretation

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**Abstract**

We explore the Many-Worlds Interpretation of quantum mechanics, beginning with a discussion of the original proposal by Everett, and extending to a discussion of modern many-worlds ideas, including discussion of some current criticisms of the many-worlds interpretation.

## Introduction

The most interesting thing about quantum mechanics: it works. Despite the fact that almost every explanation for *why* quantum mechanics actually works leads to unanswerable paradoxes, we all have faith in it. After all, it gets results, right? "Shut up and calculate!" the advisors cry. We leave the question of *why* for metaphysical thought and ponderance: the kind that blindsides you on some idle Wednesday (probably during a seminar of some kind). The Many-Worlds Interpretation of quantum mechanics was born out of such metaphysical wonderings in 1957 by Hugh Everett III, in his Princeton Ph.D. thesis. A shorter paper, *"Relative State" Formulation of Quantum Mechanics* followed later in the year, and introduced the broader physics community to the ideas of a new "metatheory" (as Everett himself described it) to the "theory" of quantum mechanics. One which posited quantum mechanics, without all that silliness of wavefunction collapse, by providing a new structure which eschewed the Copenhagen Interpretation's idea of an "external observer."

Everett's Relative State formulation was recharacterized as the "Many Worlds Interpretation" by Bryce DeWitt in the 1960s. It serves as an Everett metatheory to the theory of nonrelativistic quantum mechanics in that "it is an underlying theory in which the nature and consistency, as well as the realm of applicability, of the older theory can be investigated and clarified." [1] The Many-Worlds Interpretation attacks the most fundamental of problems of quantum mechanics: rectifying many of the apparent paradoxes that the Copenhagen formulation of quantum mechanics admits.

Everett's original intention with the theory which is presented here was the goal of unifying the realms of relativistic quantum mechanics and general relativity. So, in a sense, the Many Worlds Interpretation (MWI) is a primitive attempt at a "grand unified theory," which the physics community searches for voraciously to this day. [2]

## The Copenhagen Interpretation

Before we move into the specifics of the Many-Worlds Interpretation, we first present a lightning-fast review of the Copenhagen Interpretation (CI) basic principles. The CI essentially gives the following: a physical system is described in terms of it's state function $|\psi\rangle$, a member of a Hilbert Space (typically of square-integrable functions), and provides information to us based solely on probabilities for the results of an observation. There are two ways one of these state functions, $|\psi\rangle$, can change:

1. A continuous, deterministic change of the state with respect to time, arising from Schrödinger's Equation.

2. The discontinuous change from one state to another during collapse of the wavefunction.

The act of measuring an observable collapses the state function to an explicit eigenstate of the aforementioned observable's operator. (For example, Schrödingers cat. A cat is placed into a box with a vial of poison, such that opening the box breaks the vial and leads to kitty's untimely demise. When in the box, the cat exists as a linear superposition of $|alive\rangle$ and $|dead\rangle$. However, when we open the box, the act of observing the cat as dead (either from poison or starvation - depending on how long we left the experiment sit in the lab) places the cat into a pure eigenstate of the "death operator": $|dead\rangle$.) This is collapse of the wavefunction.

The CI is indeed powerful medicine, which works nicely for calculations, but what of it's fundamental basis as a physical theory? Why must the act of measurement change a system? It is this very question which Everett pondered:

> "This formulation describes a wealth of experience. No experimental evidence is known which contradicts it. Not all conceivable situations fit the framework of this mathematical formulation. Consider for example an isolated system consisting of an observer or measuring apparatus, plus an object system. Can the change with time of the state of the total system be described by [Process 1]? If so, then it would appear that no discontinuous probabilistic process like [Process 2] can take place. If not, we are forced to admit that systems which contain observers are not subject to the same kind of quantum-mechanical description we admit for other physical systems." [1]

What Everett claims is that in invoking the contemporary Copenhagen Interpretation, in essence we are limiting ourselves to a special class of problems, where we are unwilling to admit observers on more than some "mechanistic" basis: a light turns on, a chirp is heard, etc. where the state of our mechanical observer *does* change. This limiting of problems then is the principal weakness of the CI.

## The MWI and the Everett Postulate

The MWI foregoes the contemporary two postulate Copenhagen Interpretation, and instead adopts the Everett Postulate:

> *All isolated systems evolve according to the Schrödinger Equation:* $\frac{d}{dt}|\psi\rangle = -\frac{i}{\hbar}|\psi\rangle$. [3]

This may seem like straightforward repetition of the tenets of the CI, but there are some rather important consequences of this *single* postulate:

- The entire universe evolves according to the Schrödinger Equation. (The universe is, in as far as we can comprehend, an isolated system).
- There are no definite outcomes of measurements in quantum mechanics, since there can be no collapse of the wavefunction (it would most definitely violate the Everett Postulate).

People often regard the MWI as being completely equivalent to Everett's Relative State formulation, however, the MWI is only one of many Everett Postulate-based interpretations of quantum mechanics. The calculation of probabilities for various acts of measurement is not determined mechanistically and axiomatically as with the CI, but is instead derived from the Hamiltonian dynamics of a system by computing decoherence rates. [3]

The concept of an event having no definite outcome is one with which to wrestle: how does it make sense that nothing in the quantum universe is tenable and determinant? Philosophically speaking; is the sky not always blue? We live in a world that is macroscopic, and hence deterministic, so it makes sense that indeterminacy makes no sense. Why can we not extend our acceptance of natural indeterminacy in quantum mechanics to further acceptance that what we did think was certain - quantum mechanically - is not quite as it appears. After all, time is the thing that uncovers deeper levels of complexity, is it not acceptable to believe our understanding of uncertainty is not as certain as our physics ancestors (Schrödinger, Dirac, et al.) thought?

As a simple example, let us consider the case of an experimentalist observing the spin of an electron. Let's assume that our observer lives in the Hilbert Space consisting of the three states $|happy\rangle$, $|sad\rangle$, and $|meh\rangle$, and that the electron is either in the $|up\rangle$ or $|down\rangle$ states. Further supposing our observer has some affinity for spin-up electrons, dislikes spin-down electrons, and that a time evolution operator $U = exp(-iHt/\hbar)$ exists for our isolated experiment, we can say:

$$U|up\rangle \otimes |meh\rangle = |up\rangle \otimes |happy\rangle \tag{1}$$

and

$$U|down\rangle \otimes |meh\rangle = |down\rangle \otimes |sad\rangle. \tag{2}$$

These results would follow from the CI, however, what if our initial state of the electron was in some superposition of the $|up\rangle$ and $|down\rangle$ states, with amplitudes $\alpha$ and $\beta$ respectively? According to the CI, measuring would collapse the state of the electron into either pure-$|up\rangle$ or pure-$|down\rangle$, and the act of observing would result in one of the above final states of our observer. But according to Everett, the "final state" for our observer would remain a superposition:

$$U(\alpha|up\rangle + \beta|down\rangle) \otimes |meh\rangle = \alpha|up\rangle \otimes |happy\rangle + \beta|down\rangle \otimes |sad\rangle. \tag{3}$$

[3]

The common misconception regarding the Many-Worlds Interpretation is the at some instance the universe splits into two magic, seperate copies where one universe observed the outcome of a measurement one way, and the other universe observed the outcome to be another. This represents a fundamental misunderstanding of Everett's ideas, because this is inconsistent with the Everett Postulate: the two separate terms in Eqn. 3 could exhibit interference. According to the MWI, there is only one wavefunction, with results obtainable from that wave function by decoherence calculations alone, not postulates.

## Criticism and Conclusions

One of the common criticisms of the Many Worlds Interpretation was that it doesn't explain randomness without the sort of instantly changing states (i.e. collapse) exists in the Copenhagen Interpretation. However, Everett shows us that indeed the MWI does perceive of randomness despite the fact that the Schrödinger Equation is causal.

Another criticism often voiced is that it doesn't explain why we perceive of weird superpositions, or that the theory in general is just too weird to be true. This subjective idea of weirdness is usually based on with what philosophical basis the observer of MWI lives in; the "outside" view, that mathematical language is more fundamental than human understanding, or the "inside view", that human understanding is based on that which is physically real, and mathematics is merely our approximation of what we see. Critics of the MWI tend to be proponents of the "inside view", and are actually saying that the two opposite views tend to contrast one another, and is saying that they are uncomfortable with living in the other side.

No matter what your opinion of the philosophical nature of the universe, it is important to recognize that the MWI gaining more and more popularity and adherents within the scientific community. However, like all questioned theories it has an uncertain future. One thing we can be certain of: whether or not the final word on the structure of quantum mechanics will be the MWI or not is a moot point, as the entire idea behind science is enlightened debate about the fundamental structure of the universe, so surely metaphysical questioning of this sort will continue to be as prevalent as it is today (even if it only occurs during boring seminars).

## References


[1] Everett, H. *"Relative State" Formulation of Quantum Mechanics.* Review of Modern Physics **29**, 454 (1957).

[2] Albert, D. Z., and B. Loewer *Interpreting the Many Worlds Interpretation*, Synthese 77, pp. 195, (1998).

[3] Tegmark, Max *The Interpretation of Quantum Mechanics: Many Worlds or Many Words?* arXiv:quant-ph/09032v1, (1997).

[4] Clown, Marcus *The Illusion of Reality in a Quantum World*, New Scientist, Issue 2595, (17 March 2007).

[5] Page, Don *Can Quantum Cosmology Give Observational Consequences of Many-Worlds Quantum Theory?*, arXiv:gr-qc/0001001v1, (2000).