Understanding Many-Worlds

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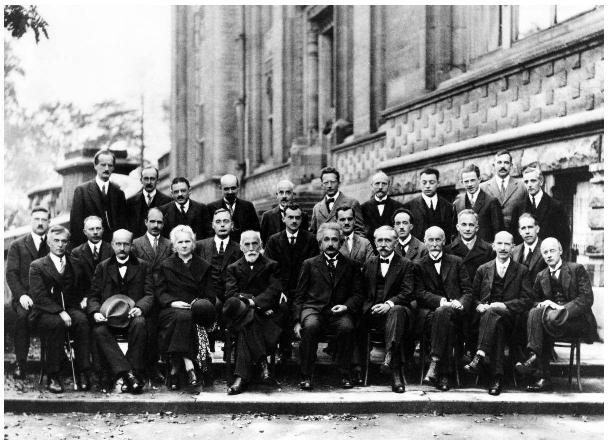

Figure 1: The 1927 Solvay conference, lauded by Heisenberg as, “officially, the completion of the quantum theory,” while Langevin remarked it was, “where the confusion of ideas reached its peak.”

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Update (30 Sep 2025): *There is now a PDF and EPUB version of the article! They're both automatically updated when the article gets updated. If there are any issues with the formatting, please feel free to reach out.*

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1. Introduction

1.1 What If All Fiction Were Reality?

You flip a coin. Heads, you text your ex. Tails, you don't. You flip it and catch it. It hits tails. You go on with your life.

But what if both outcomes happened? What if, somewhere, a version of you did send the message, and is now navigating that reality, while you sit here, relieved that you didn't?

> **Info** Of course, you wouldn't suddenly start doing random things in another version of reality—you'd still act for your own reasons. The coin is just a simple way to picture it.

Welcome to quantum mechanics, where quantum events cause the universe to split, creating a new, independent version of reality for each possibility.

This isn't metaphorical; it literally happens in our physical reality, all of the time.

There's a “you” who became a concert pianist, a “you” who never met your best friend, a “you” who died in an accident you narrowly avoided. And all of them are real.

1.2 Quantum Nonsense

Quantum physics is famously bizarre. You may have heard of Schrodinger's cat: both alive and dead, until you see it. The thought experiment posits that an outcome cannot exist until it is observed. That's the accepted story told in universities and textbooks, it's not science-fiction.

But the problem is: it's wrong.

This mainstream interpretation of quantum mechanics is often called the *Copenhagen* interpretation.

However, this name is misleading: it wasn't a single unified theory, nor solely the creation of Bohr and the *Copenhagen* school after which it's called. Pieces of it came from different people, like Bohr's idea of ‘complementarity’ (wave–particle duality), Von Neumann's collapse postulate as a stopgap measure, and later generations who mixed them into an official-sounding package.

We will thus use *collapse interpretation* to refer to this mix of ideas instead of *Copenhagen interpretation* as it's commonly called.

It's also sometimes called the “Shut up and calculate!” interpretation, due to its denial of the implications of quantum theory and emphasis on the calculatory aspect of quantum theory.

The collapse interpretation adds unnecessary and ad hoc assumptions to avoid the implications of many worlds existing. It's wrong, and we will see why in this article.

1.3 A Better Explanation

The good news is there's a better explanation—a better framework—to understand quantum mechanics. Importantly, this framework doesn't add any additional assumptions beyond quantum theory proper.

This explanation has various names. Some call it *Many-Worlds*, others call it *Everettian Quantum Mechanics*, after Hugh Everett, the physicist who proposed it in 1957. In mainstream media it's often called the *Multiverse*. Henceforth, we will refer to it as Many-Worlds.

> **Info** I have a grudge with the term *Everettian quantum mechanics*, because Everettian quantum mechanics is simply quantum mechanics, as we will see later on in this article. Adding the '*Everettian*' prefix may convey the misconception that they are different.
>
> *Many-Worlds* is preferred over *Multiverse*, as this latter term has been used in many different ways, including cosmological theories, plots for Hollywood movies, etc., which may lead to confusion.

Many-Worlds is often grouped with other "interpretations" of quantum mechanics. But unlike collapse-based views, it doesn't add extra assumptions. It simply takes the Schrödinger equation literally and universally.

For now, we'll call it Many-Worlds. Later in this article, we'll argue why it's better understood not as just one interpretation among others, but as quantum theory itself.

1.4 Who This Is For

The intended audience for this article is everyone, especially if you've never studied physics.

For the sake of comprehensiveness, we will start at the very beginning, but you're more than encouraged to skip parts that you're already familiar with or aren't of interest.

Equations will be used throughout this article. You shouldn't shy away from them. Whenever equations are introduced, they will be thoroughly covered and explained so that no one is left behind.

These equations may look scary, but remember, everything is hard before it is easy. If something feels confusing at first, that's normal—it means you're learning. Even geniuses struggle early on, and what distinguishes them is not talent, but persistence. As Thomas Edison once said: "Genius is 1% inspiration and 99% perspiration." So, always remember: no idea is inherently too complex to be understood.

In case you get lost at some point throughout the article, don't hesitate to go back and re-read the previous sections. Don't hesitate to use tools like ChatGPT to get a better understanding of certain topics. However, be warned that ChatGPT, like most physicists, unfortunately tends to irrationally favor collapse interpretations, as the collapse view is the most widely presented one on the web.

Without further ado, let's get into it.

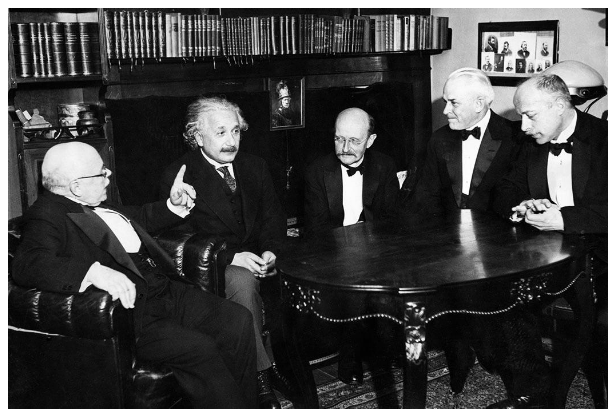

Figure 2: Albert Einstein and Max Planck (middle) together with three other Nobel laureates—Walther Nernst, Robert Andrews Millikan, and Max von Laue—captured at a dinner hosted by Laue in Berlin on 11 November 1931.

2. A History of Quantum Mechanics

2.1 Physics Before Quantum Mechanics

2.1.1 Newton and Laplace In the 17th century, Isaac Newton described nature using a set of simple mathematical laws. His laws of motion and universal gravitation explained everything from falling apples to the orbits of planets. Time and space were absolute and universal.

His work, along with the work of many others that followed, came to be known as *classical physics*

Importantly, according to classical physics, everything was deterministic: if you knew the position and velocity of every particle in the universe at one time, you could predict the future perfectly.

In the early 1800s, Pierre-Simon Laplace pushed this deterministic idea to its logical extreme. He wrote:

> *"We may regard the present state of the universe as the effect of its past and the cause of its future. An intellect which at a certain moment would know all forces that set nature in motion, and all positions of all items of which nature is composed, if this intellect were also vast enough to submit these data to analysis, it would embrace in a single formula the movements of the greatest bodies of the universe and those of the tiniest atom; for such an intellect nothing would be uncertain and the future just like the past could be present before its eyes."*
> — Pierre-Simon Laplace

This hypothetical intelligence, now called Laplace's Demon, would be able to compute the entire future of the universe from its present state. According to this conception, the universe was fully knowable and completely predictable.

2.1.2 The Limits Begin to Show The classical worldview worked astonishingly well... for a while. It explained the motion of planets, the trajectory of projectiles, and the behavior of pendulums and fluids. It wasn't until the beginning of the 20th century that cracks began to appear. Reality, it turned out, was hiding something deeper and stranger.

Here are three key examples where classical physics failed completely:

- **Blackbody Radiation:** Physicists tried to model the radiation emitted by a hot object (a so-called *blackbody*) using classical ideas. However their equations predicted that the object would emit infinite energy at high frequencies, which contradicted observations and was rightly regarded as an absurdity for theoretical reasons. This failure was known as the *ultraviolet catastrophe*, because classical theory predicted that blackbodies should glow with blinding ultraviolet light.

  The mystery was only solved when Max Planck proposed that energy could only be emitted or absorbed in discrete packets, or *quanta* (plural of *quantum*). A quantum of light is the smallest discrete unit in which light energy exists or is emitted/absorbed. This was the first seed of quantum theory.

- **The Photoelectric Effect:** When light shines on a metal surface, it can knock electrons (electrically charged particles often found inside atoms) free, a phenomenon called the *photoelectric effect.*

  Classical physics predicted that the intensity of light—its brightness–should determine whether electrons are emitted. However, experiments showed that this wasn't true. Frequency—which corresponds to the color of the light—was the actual determinant of the electrons emitted. For example, even very dim ultraviolet light could eject electrons, while bright red light could not.

  Think of a frequency as the frequency a radio is tuned into. When light is "tuned into" a certain frequency, it has a certain color, like red or blue, if the frequency is within the range that the human eye can detect. Infrared or ultraviolet light are examples of frequencies that are invisible to the human eye.

  The photoelectric effect was completely inexplicable in classical terms. Einstein resolved the mystery by suggesting that light itself comes in particles, now called photons, each carrying a fixed energy determined by its frequency. This energy is given by a beautifully simple equation: $E = h\nu$ where E is the photon's energy, h is Planck's constant, and ν (the Greek letter 'nu') is the frequency of the light.

- **Atomic Spectra:** When you heat a gas or pass electricity through it, it emits light at specific frequencies. Each frequency is a line of color, or spectral line, in a larger spectrum.

  Classical physics had no explanation for why atoms should emit only certain frequencies of light and not others. Something was wrong with the classical picture.

  The first step toward a solution came in 1913, when Niels Bohr proposed that electrons in an atom could only occupy discrete energy levels, and that light is emitted or absorbed when the electron's wavefunction changes from one level to another. This explained why atoms give off sharp spectral lines rather than a continuous smear of colors.

2.1.3 The Crisis of the Classical Worldview By the early 20th century, physicists were forced to admit that classical physics couldn't be the full story. At large scales, with the exception of extreme conditions like high speed or strong gravity, it worked beautifully, but at small scales—the microscopic level of atoms, photons, and electrons—it wasn't accurate.

> **Info** Atoms are tiny units of matter, while photons are particles of light. Notably, both exhibit wave-like behavior. A wave is a repeating pattern that spreads through space, like ripples on water.

The new explanation of microscopic reality that emerged—quantum mechanics—wasn't just a better theory.

It was a new way of understanding reality.

2.2 The Birth of Quantum Mechanics

2.2.1 Planck's Quanta As previously mentioned, Max Planck tried to solve the blackbody radiation problem, the so-called *ultraviolet catastrophe*.

Planck proposed that energy could only be emitted in multiples of a tiny unit: $E = h\nu$. In this equation, E is the energy, h is Planck's constant, and ν is the frequency of the radiation.

> **Info** Planck's constant is equal to $h = 6.626\,070\,15 \times 10^{-34}\ \frac{J}{Hz}$, where J stands for Joules, a unit of energy, and Hz stands for Hertz, a unit of frequency.

2.2.2 Bohr's Atomic Model In 1913, Danish physicist Niels Bohr built on these ideas to propose a model of the hydrogen atom that explained atomic spectra, the unique "fingerprints" of light emitted by atoms.

Bohr's model was revolutionary:

- Electrons could only occupy specific energy levels.
- Electrons didn't spiral into the nucleus as classical theory predicted.
- When electrons transitioned between levels, their wavefunction changed in such a way that they emitted or absorbed a photon with energy $E = h\nu$.

This model explained the spectral lines of hydrogen with stunning precision. Bohr's model hinted at a radical new idea: the microscopic world operates on rules fundamentally different from those that govern the macroscopic world.

2.2.3 Something Deeper Was Needed By the 1920s, physicists had a growing list of quantum "fixes": Planck's energy quanta, Einstein's photons, Bohr's energy levels, and others. However, these collectively amounted to a patchwork, rather than a single, coherent theory.

Such a theory would require a mathematical framework that could encompass all of the discovered quantum phenomena in a single language. Eventually this language was established, bringing with it a strange and abstract equation. This equation would describe an entirely novel concept in physics—the *wave function*.

Figure 3: Paul Dirac and Werner Heisenberg, likely in the early 1930s. Heisenberg created the first complete formulation of quantum mechanics and Dirac unified quantum mechanics with special relativity, among other things.

3. A Primer on Quantum Mechanics

3.1 The Wave Function

In 1926, Erwin Schrödinger introduced what would become the core equation of quantum mechanics: the Schrödinger equation.

But more importantly, he introduced a completely new object into physics, the wave function, usually denoted by the Greek letter Ψ (psi).

3.1.1 What Is the Wave Function? The wave function Ψ is a mathematical object that encodes the entire physical state of a quantum system.

Given Ψ, you can calculate everything you might want to know: how likely it is to find a particle in a given location, how it will evolve over time, or what outcomes an experiment might yield.

> **Info** A *quantum system* can be anything—for instance, a particle in a box. The wave function allows you to calculate the likelihood of finding the particle in a specific location of the box.

Here is an example of a wave function (don't be scared, it doesn't bite):

$$\Psi_n(x) = \sqrt{\frac{2}{L}} \sin\left(\frac{n\pi x}{L}\right),\ 0 < x < L\ 0,\ \textit{otherwise}$$

Don't worry if this looks imposing, you don't need to understand what is exactly happening here to understand the rest of the article.

3.2 Hilbert Space

To understand Ψ, the wave function, we need to understand the kind of space it "lives" in—the so-called *Hilbert space*.

In classical physics, a system might be described by a few numbers: position, momentum, energy. In quantum mechanics, a system is described by a vector in Hilbert space, written as $|\psi\rangle$. No need to overthink the notation, as we could have written it as x or $john$, but for reasons that we won't get into here, we write it as $|\psi\rangle$. It's just a name.

> **Info** A vector is just an object that holds multiple numbers at once.
>
> In everyday life, think of a vector like a shopping list. Instead of holding just one number, it holds several: 2 apples, 3 bananas, 1 loaf of bread (the numbers here are completely random, we could have picked any other). It's a single object (the list) that bundles together multiple values.
>
> In quantum mechanics, the vector $|\psi\rangle$ works the same way, except the "items on the list" are possible states or outcomes of the system (like different coin toss results, or different locations of a particle). Each number in the vector tells you how strongly that state is "present" in the overall mixture.
>
> So you can think of $|\psi\rangle$ as the master list of all the ways the system can exist, and how much weight each way carries.

At its core, a Hilbert space is a mathematical space where each point represents a possible quantum state of a system. It's like the stage on which quantum reality plays out.

You can think of it as 3D space, but instead of three coordinates like (x, y, z), states in Hilbert space can have infinitely many dimensions.

> **Info** If this sounds abstract, that's because it is. Here is a simple analogy: Imagine a piano keyboard that extends forever in both directions, left and right, with an infinite number of keys, each with a unique tune. A Hilbert space is like the entire infinite keyboard itself.
>
> Any sound you play (a chord, a song, noise) is a combination of those infinite unique tones—this is like a vector in Hilbert space. Just as any sound can be broken down into individual notes, any quantum state can be decomposed into simpler building blocks, called *basis states*, in Hilbert space.

3.3 The Schrödinger Equation

The Schrödinger equation tells us how the wave function changes over time. In its most common form, it looks like this:

$$i\hbar\frac{\partial\Psi}{\partial t} = \widehat{H}\Psi$$

Let's break it down:

- Ψ is the wave function (the full quantum state).

- i is the *imaginary unit*. Its value is defined as $i = \sqrt{-1}$. So $i^2 = -1$. Don't be scared of it. It's just a number, whose value is the square root of -1. No need to overthink it.

- $\hbar$ is Planck's constant divided by 2π (meaning $\hbar = \frac{h}{2\pi}$). Again, no need to overthink this, we're just taking Planck's constant and dividing it by 2π.

- $\frac{\partial \Psi}{\partial t}$ is the time derivative of Ψ, the wave function, meaning its rate of change at a specific point in time t.

- $\widehat{H}$ is the Hamiltonian operator, which describes the total energy of the quantum system. In quantum mechanics, the Hamiltonian is an operator, meaning we apply it to the wave function (this is true of all operators). Importantly, the Hamiltonian doesn't directly calculate the energy of the system. Instead, it tells you which energy levels are possible, like a rulebook listing the notes a piano can play.

3.3.1 Determinism, Linearity and Universality

The Schrödinger equation is linear, deterministic, and universal:

- **Deterministic:** If you know $\Psi(t_0)$, the state of the wave function at a time t_0, then you can compute $\Psi(t)$ for any future time t.
- **Linear:** If Ψ_1 and Ψ_2 are solutions to the Schrödinger equation, then any combination $a\Psi_1 + b\Psi_2$ is also a solution, where a and b are any real numbers.
- **Universal:** It applies to all particles or systems that can exist.

These three features, linearity, determinism, and universality, will be crucial later on.

> **Info** A solution to the Schrödinger equation is a specific wave function Ψ that satisfies the equation. In other words, it's a function that correctly describes how a quantum system (like an electron, atom, or a particle in a box) evolves over time according to quantum mechanics. Once you have this solution, you can predict how the system behaves at any moment.

While the wave function describes the physical state of a quantum system at a given moment, the Schrödinger equation allows us to track its evolution over time.

3.4 The Born Rule

One of the most famous results in quantum mechanics is the Born rule, introduced by Max Born in 1926. It tells us how to extract probability density from the wave function:

$$p(x) = |\Psi(x)|^2$$

The difference between probability and probability density is as follows: the probability of something is the likelihood of it happening, but the probability density describes the concentration of that likelihood among different values, sort of like a map showing where outcomes are more or less likely.

This means the probability density of finding a particle near position x is the square of the absolute value of the wave function at that position.

> **Info** The absolute value of the wave function just means how strong or how big the wave function is at a certain point, its magnitude, without regard to direction or sign.

For example, if you want to calculate the probability density of finding the particle near position $x = 2$, and $\Psi(2) = 0.8$, for instance, then the density is $p(2) = |\Psi(2)|^2 = 0.8^2 = 0.64$.

3.5 Superposition

In classical physics, a system is always in one definite state. A coin is either heads or tails. A particle has a specific position and velocity. Reality is singular.

Quantum mechanics, as described by the wave function Ψ, is different. A system can exist in a superposition, a single physical state that encodes multiple and simultaneous realities.

This isn't a statement about our ignorance or uncertainty. It's a statement about what is, superpositions are entirely real, evolve deterministically, and follow the Schrödinger equation at all times.

3.1.1 What Is a Superposition?

A quantum system can be described as (again, don't worry about the weird notation):

$$|\psi\rangle = a|A\rangle + b|B\rangle$$

The above equation is an example of a superposition. $|A\rangle$ is one outcome, $|B\rangle$ is another outcome, and both outcomes are equally real.

Imagine having a coin where neither face is just heads or just tails, but instead, both at once, not because the state of the coin's face is unknown, but because the outcomes exist in a blended state.

Let's say that $|A\rangle$ is heads and $|B\rangle$ is tails. The numbers a and b, called *amplitudes*, tell us how much of $|A\rangle$ and $|B\rangle$ are in the mix relative to each other. The amplitudes are like proportions of ingredients in a recipe, and indicate how much of each outcome (ingredient) the system has.

However, we don't see both outcomes when we look. We'll come to that later.

Figure 4: Portrait of Erwin Schrödinger.

4. Why the Collapse Interpretation is Wrong

4.1 What the Collapse Interpretation Claims

Before we can dismantle the collapse interpretation of quantum mechanics, we need to understand what it actually claims.

To be clear: this section is *not* an endorsement. These ideas will soon be shown to be inconsistent, unnecessary, and in direct conflict with the literal meaning of quantum theory. But it's important to accurately state what the collapse interpretation view says, and what generations of physicists have been taught to accept without question.

The collapse interpretation asserts that the wave function Ψ, while useful for predicting probabilities, is not real. According to this view, Ψ is a tool for calculating the probability density of various outcomes (using the Born rule), but not a description of the system itself.

The defining feature of the collapse interpretation is of course the collapse postulate: *the wave function evolves smoothly and deterministically only until a measurement is made. Then, randomly collapses into one of its outcomes, and all other outcomes are destroyed.*

This collapse is instantaneous and non-deterministic. Before collapse, a system might be in a superposition, like the example from earlier:

$$|\psi\rangle = a|A\rangle + b|B\rangle$$

After a measurement, one of the outcomes, say, heads, remains:

$$|\psi\rangle = |A\rangle$$

The other possibility, tails, is considered to have "disappeared." The wave function no longer describes both outcomes, only one is real. This abrupt change is not derived from the Schrödinger equation, it's an addition. To be clear, this is not a minor technical point, it requires introducing a separate rule for quantum systems once observed:

- Deterministic Schrödinger equation when unobserved.
- Random collapse when observed.

In other words, according to the collapse interpretation view, the Schrödinger equation applies everywhere and at any point in time, *except* when an observation is made.

4.2 The Observer as a Magical Boundary

According to the collapse interpretation, collapse occurs when an "observation" is made, but what qualifies as an observation, and who, or what, counts as an observer?"

It's here that things get suspicious. The collapse interpretation never provides a clear, physical definition of a measurement or an observer. The theory assumes this boundary but refuses to say where it lies. Is it the eye? The brain? A camera? A Geiger counter? A thermometer? Consciousness?

It gets even worse: observers themselves are made of quantum particles!

The collapse interpretation avoids resolving these issues by simply declaring that somehow collapse happens when it needs to, and that the details don't matter.

Hence why it's called by many the "Shut up and calculate!" interpretation. But the cost of shutting up is blocking decades of scientific progress.

4.3 Mathematically Ill-Defined

It's important to emphasize that collapse contradicts the core equation of quantum mechanics, the Schrödinger equation.

As seen in *section 3.3*, the Schrödinger equation is:

- **Linear:** superpositions evolve linearly. Their parts may interfere or cancel, but they never collapse on their own.
- **Deterministic:** there is no randomness in the equation.
- **Universal:** the Schrödinger equation applies to all physical systems. Planets, labs, and observers are built from atoms, and atoms are quantum systems, so the whole remains quantum.

Collapse violates these features, as it's:

- **Non-linear:** it destroys all but one term.
- **Non-deterministic:** it introduces randomness with respect to measurement outcomes.
- **Non-universal:** it happens only when "observed," but never explains what that means physically.

Importantly, the collapse mechanism isn't derived from anything. It's injected by arbitrary fiat.

And as shown through the violation of linearity, determinism and universality, it's not just an unneeded philosophical add-on. It's physically incoherent and mathematically ill-defined—an extra rule with no place in the framework of the Schrödinger equation.

4.4 The Logic of Scientific Inertia

Frustratingly, the collapse interpretation answers the question, "What happens in a quantum system?" with, "Whatever we happen to see." It relies on an undefined observer and a discontinuous rule that cannot be derived from the theory's core equation.

Schrödinger himself described it as "patently absurd" that the wave function should "be controlled in two entirely different ways, at times by the wave equation, but occasionally by direct interference of the observer, not controlled by the wave equation."

So, why is it still so popular if it's so wrong?

The collapse interpretation became entrenched because:

- **The math works:** Quantum mechanics makes extremely accurate predictions and for decades many thought collapse was necessary to connect the equations to the Born rule.
- **Questioning foundational assumptions is considered philosophical:** Therefore a distraction or even a threat to one's career.
- **Philosophical discomfort:** Many-Worlds implies that all possible outcomes happen. That there are countless versions of you. This feels crazy.
- **Institutional tradition:** The collapse interpretation was canonized early on. Challenging it meant challenging the authority of Bohr, Heisenberg, and generations of physicists.

The strongest reason, by far, is that fear of ridicule for proposing different views or engaging with the philosophical questions poisoned the first generation of quantum physicists, and has been passed on ever since.

Academia, unfortunately, thrives on status. Talking about "many worlds" sounds like science fiction, and credibility is vital in the academic world. But science is not about comfort or credibility. It's about truth. And the truth is this: when you stop denying reality and start taking quantum mechanics seriously, you get Many-Worlds.

5. The Theory of the Universal Wave Function

5.1 Everett's Insight

In 1957, a 26-year-old Princeton graduate student named Hugh Everett III published what would become one of the most important papers in the history of physics.

Everett's radical proposal was stunning in its simplicity: *Take the Schrödinger equation seriously. Apply it to everything. Never collapse the wave function.*

Everett asked: What if we stop treating measurement as a special exception to the rules of physics? What if we treat observers, whether humans or instruments, as quantum systems unto themselves, obeying the same deterministic laws as everything else?

After all, as stated in *section 3.3*, nothing in quantum theory indicates that the Schrödinger equation shouldn't apply everywhere.

The implications of his simple insight were extraordinary.

5.2 Measurement Without Collapse

So, what actually happens when you perform a measurement, if it's not collapse? Everett's answer was simple: nothing out of the ordinary. Measurement is just another physical interaction, one quantum system interacting with another, governed entirely by the Schrödinger equation.

Suppose you have a particle $|\psi\rangle$ in a superposition of two outcomes $|A\rangle$ and $|B\rangle$:

$$|\psi\rangle = a|A\rangle + b|B\rangle$$

Now, let's suppose that you bring in a measurement device, such as a detector, or even just your own eyes. That measurement device is itself a quantum system, and so is also described by its own wave equation. Let's assume the device (or your eyes) to initially be in the state:

$$|D_0\rangle$$

> **Info** Here, again, $|D_0\rangle$ is just a name. We could have called it anything else. We only chose the letter D because it's the first letter of *device*.

When the particle interacts with the device, the universal Schrödinger equation doesn't collapse anything. Instead, it entangles the two:

$$|\psi\rangle = a|A\rangle|D_A\rangle + b|B\rangle|D_B\rangle$$

> **Info** *Entanglement* means that their outcomes are no longer described by independent wave functions. In the above example, $|A\rangle$ and $|D_A\rangle$ are tied together. Same for $|B\rangle$ and $|D_B\rangle$.

Here's what the entanglement signifies:

- If the particle is in state $|A\rangle$, the device registers "A", which is why we write it as $|D_A\rangle$. It's tied to the state $|A\rangle$—it's *entangled* with it.
- If it's in state $|B\rangle$, the device registers "B", which explains why we write it as $|D_B\rangle$.

There is no collapse here. Instead, there is just entanglement, and two equally real outcomes.

Further, if an observer was in the room, say initially in the state $|O_0\rangle$, they would become entangled as well:

$$|\psi\rangle = a|A\rangle|D_A\rangle|O_A\rangle + b|B\rangle|D_B\rangle|O_B\rangle$$

Figure 5: Portrait of Hugh Everett, who in 1957 released the paper "The Theory Of The Universal Wave Function", which later became known as Many-Worlds.

What the above equation says is: there is a *branch* where the device measured outcome $|A\rangle$, and the observer subsequently became entangled with that branch. There is another branch where the device measured outcome $|B\rangle$, and the observer subsequently became entangled with that one as well.

Taking things literally, without fear of the implications, this means that there are now *two* observers: one who observed and became entangled with state $|A\rangle$, and another who observed and became entangled with state $|B\rangle$.

Both are equally real, but they can't interact with each other (we will see why later). Importantly, until the exact moment that the entanglement occurred, the observer was one person, however, once the entanglement happened, two versions of the same observer emerged.

> **Info** Think of it like a book that splits into two storylines. Up to chapter 5, there's only one character, Bob. At chapter 6, the story splits into two parallel plotlines: in one version Bob opens the red door, in the other he opens the blue door. Both stories exist in the book, written side by side, but each Bob only experiences the one inside his storyline.

That's what the equation is saying: both Bobs exist, both are equally real, each is restricted to the outcomes of their own branch, in their own *world*.

This might seem crazy, but all we're doing here is taking quantum mechanics seriously and figuring out its implications. There are no additional, ad hoc assumptions here.

This is why calling Many-Worlds an 'interpretation' is misleading. It is quantum theory taken literally. Collapse interpretations, by contrast, are extra rules pasted on top.

We will cover later on in the article where each version of Bob resides, and why they can't communicate with each other.

But first, if an observer in the room becomes entangled with each branch, what about the rest of the world? Won't it eventually become entangled as well? The answer is, yes, but before that, let's go over what *interference* is.

5.3 Interference

Superpositions don't just list the different possibilities. Their amplitudes—the "weights" of each possibility—can also interact with each other. This interaction is called interference.

Think of two ripples on a pond. When the ripples meet, they can either converge into a larger ripple, a form of *constructive* interference, or they can cancel each other into still water, a form of *destructive* interference.

More formally, suppose you have a particle $|\psi\rangle$ in a superposition of two outcomes $|A\rangle$ and $|B\rangle$:

$$|\psi\rangle = a|A\rangle + b|B\rangle$$

Here a and b (the amplitudes) aren't just passive numbers. How they combine will determine whether in some situations $|A\rangle$ and $|B\rangle$ constructively interfere or destructively interfere.

In practice, this means that before decoherence kicks in, a phenomenon we will shortly go over, branches have sufficient *overlap* in order to interfere. When decoherence kicks in, they become independent worlds and no longer have the ability to interfere.

5.4 What Is a "World" in Many-Worlds?

In *section 5.2* we covered an example of a device becoming entangled with each possible state of a particle $|\psi\rangle$, with the observer in the room eventually becoming entangled as well. But what about the rest of the world?

Eventually, the rest of the world will become entangled as well. The measuring device may emit heat, for example, the amount of which depends on the device's measurement outcome. Heat gets air molecules to be more "excited", and, as a result, they bump into each other more. This results in the air molecules becoming entangled with the original particle's state as well.

Over time, the disturbance ripples outward—molecules colliding, photons scattering, and even the underlying fields (like the electromagnetic field) extending—so that larger and larger parts of the environment become correlated with the original outcome. Because nothing is perfectly isolated, the entanglement spreads far beyond the device.

It's not literally the entire universe all at once—what actually happens is that ever-larger subsystems become independent bubbles of history. Each 'world' is one such bubble, expanding as more of its surroundings get locked into its storyline.

In the above example, I used the device's heat as an initial trigger, but it could have been anything. Photons could have become entangled with the device, if it reflects light. The arrangement of the atoms that make up the device could be slightly different depending on the measurement, causing the photons to reflect slightly differently. As a result, the rest of the environment would become entangled over time, just like in the previous air molecule example.

The important point here is that microscopic differences in the device after the measurement, eventually ripple into large macroscopic changes, entangling the environment with each state.

Eventually, the whole world gets entangled with each branch, meaning there are now two worlds. One world entangled with state $|A\rangle$, and another entangled with state $|B\rangle$. We call this process of growing entanglement and the separation of branches *decoherence*.

> **Info** Decoherence is what happens when a quantum system becomes entangled with its environment in so many uncontrollable ways that the different branches of its wave function can no longer interfere with each other.
>
> In plain words: it's the process by which quantum possibilities (like outcome $|A\rangle$ and outcome $|B\rangle$) stop overlapping and start behaving like separate, classical realities.

It's important to stress that splitting is local, not global. The whole universe doesn't branch at once. The chain starts right where the measurement happens: a particle hits the device and entangles it to a branch, and as photons bounce differently in each branch, the air molecules scatter differently in each branch.

The branching then propagates outward at the speed of these interactions (though never faster than light). That's why, in the Bob example, "two Bobs" only exist from the moment Bob himself becomes entangled with the device. Before that, there was still just one Bob, even though there were already two devices (assuming the particle already hit the device).

5.5 Re-interference

We now know how splitting works, and how a microscopic branch split eventually leads to completely separate and independent worlds.

But if worlds split, can they ever come back together again? Could the two Bobs merge back into one later on?

The answer is, yes! The Schrödinger equation is linear, which means that when different parts of the wavefunction evolve, they don't erase each other, they just separate. All the information about each branch is still present in principle. So re-interference is possible: If you could take every particle, photon, and atom in both branches and put them back into exactly the same state, the two branches would interfere again, merging back into a single branch.

However, this happens *extremely* infrequently. Recalling the example from *section 5.3*, a microscopic difference like a trillionth of a Celsius degree can get one air molecule to behave just slightly differently, bumping into others slightly differently as a result, entangling them. Then *those* air molecules will entangle still others, and so on.

For re-interference to happen, you would have to bring every single particle back into the original state. That's nearly impossible in practice, especially given the exponential nature of entanglement. You would need to be very quick in order to stop the chain of events and reverse the entanglement.

For this reason, re-interference is possible in simple, isolated systems, where we carefully shield the studied particles from the environment, but for macroscopic systems, like a device, an observer, and a room full of air, it's beyond reach, at least at the moment.

So while re-interference is never ruled out by the laws of physics, decoherence spreads entanglement so fast and so completely that for anything larger than a handful of particles, the worlds may as well be permanently separate.

6. Myths and Misconceptions About Many-Worlds

6.1 Do the Worlds Exist in Other Dimensions?

It's a myth that Many-Worlds implies merely a collection of spatially distant, causally separated bubble universes.

All Everettian worlds, all of the constantly differentiating and emerging branches, exist in the exact same reality we live in. They overlap the same physical space we're in.

This obviously sounds insane—why can't we see them or interact with them?

The answer has to do with Hilbert space, which we covered in *section 3.2*. As you know by now,

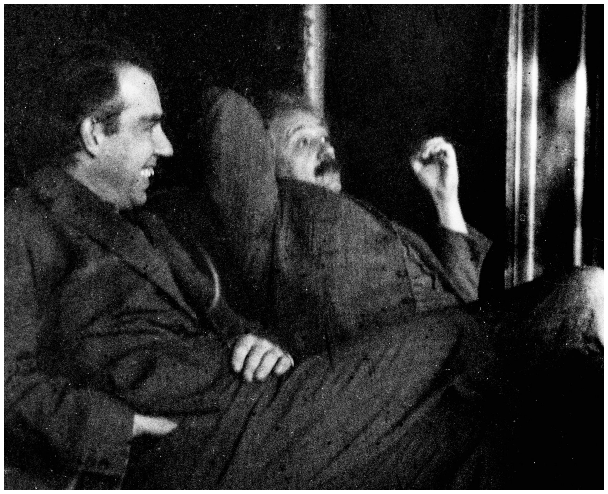

Figure 6: Niels Bohr (left) with Albert Einstein (right) at Paul Ehrenfest's home in Leiden, December 1925. Bohr strongly defended the collapse interpretation, while Einstein rejected it, arguing the theory was incomplete.

every quantum state resides in Hilbert space. Mathematically, the phenomenon of branching caused by decoherence is just quantum states in Hilbert space becoming orthogonal to each other.

Those who remember high school math may think of orthogonality as a 90º angle between two lines, making it a right angle and the lines perpendicular to each other. This is the case here, but it also means something more abstract and deeper: the states are completely independent and non-overlapping.

Think of two songs playing on totally different radio frequencies. They both fill the air of the same city, but because they're on separate channels, your radio only ever picks up one. In this analogy, you are the radio (not to insult you), tuned into a specific branch.

In Hilbert space, orthogonal states are like those separate radio channels. They exist together, in the same exact physical space, but they don't interfere with each other. Your radio is *tuned* into a specific frequency, just like decoherence *tunes* the environment into specific branches.

This is all very mathematical and fine, but how is it even possible? How is it possible that there are trillions of or infinite overlapping worlds that exist in the same reality we are in, but that we can't touch them or interact with?

The reason is that, as explained above, once states become orthogonal through decoherence, all possible interference between them vanishes. Even if you tried to "peek" into another branch, you couldn't, as your eyes, your neurons, and the photons that reach you, are all already entangled with your branch.

The entire chain of your perception is locked into one storyline. From the inside, you only ever experience your branch, never the others.

Additionally, the issue of non-interaction comes down to practical impossibility. In order to interact with another branch, you would need to reverse every single entangling interaction that separates them, every scattered photon, every vibrating atom, every air molecule collision. At a macroscopic level, this is essentially impossible, as explained in *section 5.4*.

So, the reason that you don't feel molecules from other worlds hitting you is because "those molecules" don't even exist in your branch. They exist in their own orthogonal state, evolving in their distinct and independent branch.

If you are having trouble visualizing this or understanding this, don't worry, it's normal. Again, we made no additional assumptions here. And, for what it's worth, black holes, spacetime, and other phenomena in physics are at least as counterintuitive as this.

6.2 Why Don't I Notice the Split?

By now you might be wondering: If I split into two versions of myself whenever a measurement happens, why don't I feel the splitting? Shouldn't I feel something when a new "me" appears?

The reason is simple: from the inside of a branch, there is nothing to notice or feel. Each copy of you is perfectly continuous with your past and is only aware of what happens in that particular branch.

Going back to Bob's example from *section 5.2*: Before the measurement, there was one Bob in state $|O_0\rangle$.

After the device's measurement, the wave function branched and subsequently entangled Bob along with it:

$$|\psi\rangle = a|A\rangle|D_A\rangle|O_A\rangle + b|B\rangle|D_B\rangle|O_B\rangle$$

Now there are two Bobs: Bob A and Bob B. But each one remembers being the original Bob. Each one experienced a smooth, uninterrupted flow of time. Neither has any sense of "splitting."

Why? Because everything that makes up "you" has already been entangled: your eyes, neurons, memories, etc. When the split happens, each version of you carries forward the same memories up to that moment. Within each branch, it feels like nothing unusual happened. It just seems as though "one outcome" occurred.

So why don't you notice the split? Because noticing requires comparison, and you never have access to the other branch to compare it with. The only way you could notice would be if the wavefunction actually broke its smooth, reversible evolution—as if it really collapsed. But it never does, so nothing appears out of the ordinary.

That's why your everyday experience feels "normal", even though the universal wave function is constantly branching.

6.3 Is Energy Conserved If Worlds Multiply?

If there are constantly new branches being created, aren't we creating new energy all the time out of thin air?

This is one of the most natural objections to the Many-Worlds explanation of quantum mechanics. Its resolution is admittedly difficult to grasp intuitively. It *feels* like branching should mean that more and more energy appears: two worlds, two Bobs, two devices, twice as much matter and energy.

The reality, though, is that at the level of the universal wave function, the mathematical object that describes all branches, energy is perfectly conserved. The Schrödinger equation that governs its evolution guarantees that the total energy of the universe never changes.

To see how this works, let's use a very simple example. Suppose the universal state is

$$|\psi\rangle = a|A\rangle + b|B\rangle$$

with two possible branches, $|A\rangle$ and $|B\rangle$. Remember, a and b are called the amplitudes of the branches. They aren't just arbitrary numbers: their squared magnitudes, $|a|^2$ and $|b|^2$, represent the "share" of the total wave function taken up by each branch. This is another case of the Born rule, which we saw in *section 3.4*.

Now, one of the most important properties of any wave function is that it must be *normalized*. Normalization simply means that when you add up the shares of all possible branches, you get exactly 1:

$$|a|^2 + |b|^2 = 1$$

This ensures that the probabilities of all possible outcomes always add up to 100%, meaning the whole state of the wave function always represents 100% of reality, no matter how many branches it splits into. Without it, we would assign either too little or too much total probability, which would make no physical sense.

Let's make this concrete. Suppose the total energy of the universal state before branching is 10 J, where J denotes *joules*, a unit of energy. After branching, each branch looks like a complete world from the inside, with as much energy as its 'parent' branch had had: say $E_A = 10\ J$ and $E_B = 10\ J$. To Bob A and Bob B, nothing seems to be missing, and everything is continuous. Each Bob lives in a complete-seeming world.

But when we calculate the total energy of the universal wave function, we don't just add $E_A + E_B$. That would be double counting, since the 'weight' of the parent branch is equal to the sum of the 'weights' of the branches that include Bob A and Bob B. The correct calculation, then, is the *expectation value,* the average of all the possible outcomes of a measurement as weighted by their likelihood:

$$E_{total} = |a|^2 E_A + |b|^2 E_B$$

If, for example, $a = b = \frac{1}{\sqrt{2}}$, for example, then each branch has weight:

$$|a|^2 = |b|^2 = \left|\frac{1}{\sqrt{2}}\right|^2 = \frac{1}{2}$$

So, the total energy is:

$$E_{total} = \frac{1}{2} \cdot 10 + \frac{1}{2} \cdot 10 = 5 + 5 = 10$$

Energy is conserved, as promised. The "two worlds" didn't double the energy. Rather, the amplitudes rebalanced their contributions so that the universal total stays constant.

A common question at this point is whether energy is somehow "transferred" from a parent branch into its child branches. If the original world had 10 J, and each child world also has 10 J, then it may seem as if something must have been duplicated and handed out.

But that picture is misleading. Before branching, the state was a single vector $|\psi\rangle$. After branching, it is still a single vector $|\psi\rangle$, just written as a sum of components $|A\rangle$ and $|B\rangle$. At no point is energy taken from one and given to another, the global expectation value of energy is constant throughout.

6.4 At What Speed Do Worlds Split?

When we talk about worlds branching, it might sound as if the universe suddenly duplicates itself in an instant. But this is not how branching works.

Worlds don't split all at once nor in every place simultaneously. Splitting is a local and continuous process, unfolding as particles interact with their surroundings.

Each time a particle collides, or a photon interacts with something, information about the outcome is copied into the environment, and the corresponding branches grow more orthogonal (meaning more distinct) to one another.

The "speed" of branching is therefore just the speed of physical interactions:

- Photons carry outcome information at the speed of light.
- Air molecules spread information at their thermal speeds (hundreds of meters per second).
- Vibrations in solids transmit information at the speed of sound in the material.

Branching propagates outward at those speeds. There is no global cosmic moment at which "the split happens."

Instead, the process ripples outward from the site of the quantum event, like concentric waves on a pond after a stone is thrown in. But quantum branching is not caused by just one stone—it's caused by trillions, scattered everywhere, making ripples all the time. Every photon, every air molecule collision, every atomic vibration is another "stone," creating its own expanding ripples of branching.

For macroscopic systems, this all happens incredibly fast. A dust grain floating in air can decohere in less than a billionth of a second. To us, that is indistinguishable from instant. This explains why everyday reality feels so definite. Branching happens on timescales far shorter than human perception could ever detect.

Additionally, branches don't drift through space and collide with each other. Instead, what's spreading is entanglement: when a quantum event happens, information about its outcome ripples outward at the speed of interactions (light, molecules, vibrations).

If that ripple reaches you later, you don't "merge with another branch." Instead, you split at that moment, becoming correlated with that earlier event. In this way, branching is continuous and local, with new splits layering on top of old ones.

6.5 Is There a Finite or Countable Number of Worlds?

Many-Worlds is often pictured as a collection of a vast, even infinite, number of parallel universes you could (in principle) list and manually count.

But that is wrong. Branches are not fundamental objects in the theory. Those are downstream from the universal wave function, which evolves smoothly and deterministically.

> **Info** In fact, Hugh Everett named his revolutionary 1957 paper "The Theory of the Universal Wave Function", and didn't mention the existence of other universes even once throughout the entire paper. It is implied by quantum mechanics, as an emergent description, but not a fundamental part of it.

Branches are an emergent description we use when decoherence makes parts of the wave function effectively independent. They are patterns in the mathematics of the wave equation, not individually labeled "things" that physics keeps a register of. This doesn't mean they aren't real—they very much are. It just means there isn't a database or registry somewhere of all branches.

Every possible microscopic detail of the environment defines another way the wave function can decohere. There is no line where you can stop and say, "Here is the exact number of worlds." It's effectively infinite.

So while it's fine as a shorthand to say "a world where Bob saw A" and "a world where Bob saw B," in reality there are infinitely many slight variations entangled into those states, each differing by the paths of countless photons, molecules, and atoms. Talking about a "number of worlds" is like asking, "How many waves are in the ocean?"

6.6 Can We Interact with Other Worlds?

Another common myth about Many-Worlds is that, while we can't interact with other branches *yet*, perhaps some future technology might allow us to cross over or send a message, like building a radio tuned to another universe.

The answer is no. Once branches become orthogonal through decoherence, they no longer interfere. Orthogonality means that they occupy completely independent directions in Hilbert space.

No process allowed by quantum mechanics can cause two orthogonal states to overlap again unless you perfectly reverse every single entangling interaction or through some different chain of interactions that happens to bring them back together. For a macroscopic system, that is in practice impossible.

From the inside, this means your awareness is always locked to a single branch. Your eyes, neurons, and every photon reaching you are already entangled with your branch's history. There is no way to "look sideways" into another branch, because the very act of looking is part of what entangles you to this one.

Decohered worlds are effectively like radio channels on different frequencies. Both fill the air, but once you're tuned into one, you cannot hear the others.

Figure 7: Portrait of John Von Neumann, who gave quantum mechanics its precise formal structure.

7. Can Many-Worlds Be Tested?

7.1 Misunderstanding What "Proof" Means

When people first hear about Many-Worlds, their first reaction is often: *"But you can't prove it! You can't see the other worlds, so it's just speculation."*

Technically, there is a way to test it. David Deutsch, the father of quantum computing, showed so here (see *8. A Thought Experiment*). But it relies on technology we don't possess today and probably won't possess in the near future.

In any case, this objection sounds powerful, but it rests on a fundamental misunderstanding of how science works. Science is not about directly observing every part of reality. It's about conjecturing theories that explain what we *do* observe in terms of entities that we do *not* observe, and then testing those theories against experiments.

We never directly observe most of the entities science deals with. No one has ever seen an electron with the naked eye. No one has touched spacetime curvature. We infer their existence because the theories that invoke them explain our observations better than all rival theories that don't.

By this standard, Many-Worlds is not speculative at all. It is simply quantum mechanics taken seriously, without ad hoc additions or fixes. The Schrödinger equation is one of the most precisely tested laws in all of science. It has never once failed an experimental test. As previously mentioned, Everett's insight was simple: don't add collapse, just apply the equation universally.

7.2 Collapse Requires Extra Assumptions

If you deny Many-Worlds, you will probably accept collapse as an alternative "explanation". But collapse is not written in the mathematics of quantum mechanics. It is an extra rule, pasted on top.

The problem is that collapse rules are vague and contradictory: When exactly does it happen? What counts as a measurement? Why should observers or consciousness have special powers that no other physical system has?

There are no clear, testable answers. Collapse is not just an unnecessary assumption, it's one that directly contradicts the linear, deterministic, universal nature of the Schrödinger equation.

This is why Many-Worlds is not a speculative add-on. It is the default reading of the equations. If you take the Schrödinger equation and follow it through consistently, you arrive at Many-Worlds automatically. The burden of proof lies not on Everett, but on anyone who wants to *change the equations* by injecting collapse.

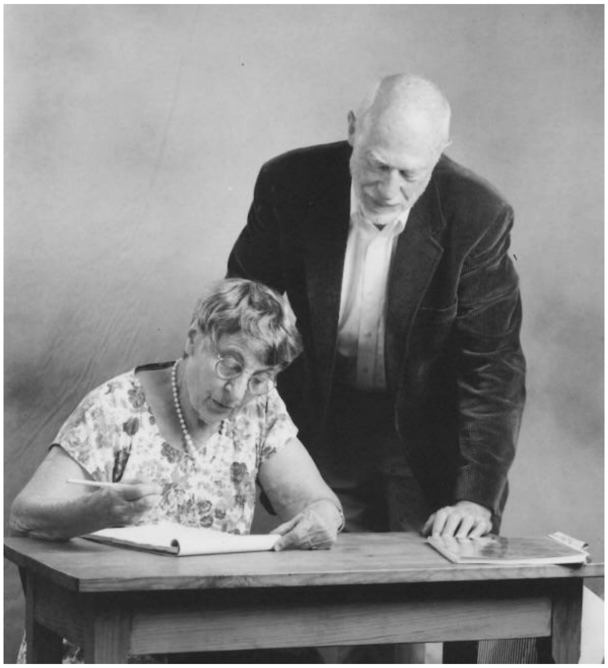

Figure 8: Bryce DeWitt with his wife Cécile DeWitt-Morette. Bryce DeWitt revived Everett's Many-Worlds interpretation and helped gain it recognition.

8. Living in Many-Worlds

8.1 Probability, Free Will, and Ethics

What does probability even mean if all outcomes happen? Is there free will—do my choices and ethics still matter?

First, it's important to clarify that while there is practically an infinity of other worlds, they each respect the laws of physics. So all outcomes *within the laws of physics* happen.

Second, we must distinguish between two perspectives. From the outside, looking at the universal wave function, there is no randomness at all. The Schrödinger equation is fully deterministic: the state evolves continuously and smoothly, splitting into branches, etc. From that global view, nothing is uncertain.

From the inside of a branch, it's impossible to know which outcome you will experience in advance. Before a quantum event, there are multiple possible future versions of you, each tied to a different outcome. You can't predict which "you" you will become, creating uncertainty. That subjective uncertainty corresponds to the probabilities of outcomes. The Born rule, as seen in *section 3.4*, tells you how much "weight" each outcome has in the universal wave function, which translates directly into how likely you are to find yourself in that branch.

Some worry that if everything happens, then nothing we do matters, as if we're passengers on a train of predetermined splits. But free will is branch-relative. Inside your branch, you still make decisions, and those decisions still cause real effects in that branch. The fact that other versions of you are making different choices in other branches doesn't reduce your agency, instead, each version of you is a genuine continuation of the original, exercising choice in their own storyline.

This leads naturally to ethics. In Many-Worlds, your actions still matter deeply. Not in some vague spiritual manner, but concretely and practically. When you choose to help someone, you shape the future of the branch in which you did so. There may be other branches in which you didn't, but that doesn't erase the fact that, in this branch, real people benefit from your action. The existence of other branches doesn't trivialize morality. In fact, it multiplies morality's scope, as your choices in this branch impact all future branches that claim this branch as its ancestor.

So probability, free will, and ethics all survive in Many-Worlds. Probability is your uncertainty about which branch you will find yourself in. Free will is your power to act within your branch. Ethics is the recognition that, in each branch, your choices define the futures that real people, real versions of you and everyone else, will live.

8.2 Fiction and Reality

One of the most unsettling implications of Many-Worlds is that, within the laws of physics, every possible outcome actually happens somewhere. There are deplorable worlds where the Nazis won World War II, Napoleon triumphed at Waterloo, etc.

But, again, fiction that violates the laws of physics, like faster-than-light travel or dragons breathing fire by magic, doesn't happen. What does happen are all sequences of events that remain consistent with quantum mechanics. The scope is vast beyond comprehension, but it's not unconstrained.

This framework does lead to interesting observations. There are universes in which what *seems* like magic happens. There are worlds, for example, where someone jumped from a skyscraper and successfully flew in the air for 30 seconds due to an extraordinarily unlikely air configuration.

In each of these cases, what appears supernatural from inside those branches, what seems like magic, is in reality just extraordinarily unlikely coincidences. The laws of physics are never violated, and the branches in which these events happen have an astronomically small weight compared to the overwhelming number of "ordinary" branches in which those events did not coincidentally align.

8.3 A Brief Explanation of Quantum Computing

Ordinary computers are made out of millions of bits, which you can think of as tiny switches that are either on (equal to 1) or off (equal to 0).

Quantum computers are fundamentally different because they don't operate on bits, but on qubits. Qubits are quantum states that can be in *superpositions* of 0 and 1, meaning not just 0 and 1, but any combination of the states 0 and 1 (as long as their respective weights add up to 1), as explained in *section 3.5*.

Qubits can be made out of many things, including photons, electrons, atoms, etc. That's why there are a lot of different approaches to quantum computing, as different companies use different systems and approaches.

Now, people often make the mistake of saying that a quantum computer works by "making the computations across many different parallel universes at once." It's a nice metaphor, but that's not how it works in practice. The real source of quantum computing's power is interference between universes.

When a quantum computer performs a computation, it creates a state of superposition. By carefully arranging the computation, we can ensure that in almost all branches, the wrong answers cancel out, while the correct answer reinforces itself.

You can compare quantum computing to creating waves in a pond: if you do it badly, the ripples collide chaotically and nothing comes out of it. However, if you do so with precision, you could get the waves to ripple against each other in such a way that most cancel each other out and a particular pattern, for example a circle, emerges. That's what a quantum algorithm is: a recipe for arranging interference across the different branches of a superposition so that only the right answers survive.

As for why many quantum computers need to be cooled at extraordinarily low temperatures, that's due to thermal noise. At nonzero temperature, particles jiggle around, because heat drives movement. These random excitations can knock a qubit out of its delicate quantum state, causing decoherence or errors. Cooling reduces the energy available for these unwanted excitations, making qubits more stable.

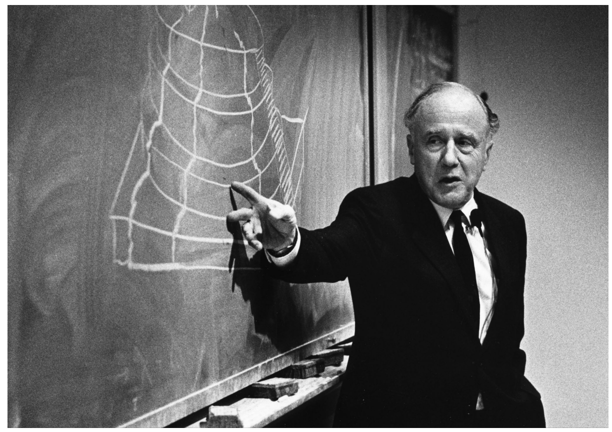

Figure 9: John Wheeler, legendary physicist and one of Everett's mentors.

9. Conclusion

Quantum mechanics is often described as the strangest theory in science. But the real strangeness isn't in the equations, it's in how people have historically resisted taking them seriously. For nearly a century, physicists have added unnecessary collapse rules.

As we've covered, following the Schrödinger equation and taking it seriously, arrives at a breathtaking conclusion: reality is constantly branching, splitting into worlds upon worlds. Every possibility consistent with the laws of physics is realized somewhere. Every choice you might make is played out in full.

It means that there are countless versions of you, living out different futures, and that miracles and tragedies, as unlikely as they seem, happen in some branches.

But it also gives us something profound. It shows us that reality is richer than we ever could have imagined. The world we see is merely a grain of sand in an immense structure described by quantum theory, an endless tapestry of realities, woven by the Schrödinger equation. An infinite, beautiful reality.