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Narrative & Argument
Fall 2011

# Informational Writing

*A paradox is only a conflict between reality and your feeling of what reality 'ought to be.'*
*Richard Feynman*

Schrodinger's Cat is one of the most widely referenced and yet poorly understood concepts in all of modern physics. He is no ordinary cat; he is alive and he is dead. His sympathetic condition evokes the stuff of science fiction, but he not a fantasy. He is a hypothetically real cat in a hypothetically sealed box, exposed to a hypothetically cruel experiment for the sake of human understanding. Who would put a cat in a box with a vial of poison, and why? And, furthermore, how did this innocent cat force physicists to repair the strained relationship with intuitive reality they had been all too willing to neglect in the beginnings of their love affair with Quantum Mechanics?

Schrodinger's Cat is a famous **thought experiment** named for the physicist who endeavored to illustrate, through the absurdity of the example, the strangest implications of Quantum Mechanics. Physicists have long employed thought experiments to mentally explore the consequences of a particular theory without the intention of actually executing the experiment, or even requiring that it be possible in the first place. Thought experiments are often used to expound new theories or illuminate key concepts, but this particular paradox was meant instead to raise questions and poke around the uncomfortable edges of Quantum Mechanics, where discoveries were being made one after, bringing physicists closer to certainty but simultaneously committing them to accept stranger and stranger implications. Before Schrodinger introduced his cat, physicists accepted these strange implications based on their trust in the mathematical and empirical evidence, but they had not yet engaged their intuition on the subject to flesh out the full complexity of its meaning, perhaps because it was both difficult for them to do so and in many ways counter to their instincts as 'men of science.'

Unlike the obscure field it was meant to question, Schrodinger's Cat is relatively accessible to those without physics degrees; the details of the physics itself are not necessary to appreciate what Schrodinger's thought experiment meant to physicists. It's worth getting to know this cat and the questions he raised about the nature of existence because the early twentieth century physicists working in Quantum Mechanics might not have questioned it without him.

In 1935, Erwin Schrodinger was inspired to craft his famous experiment as a response to developments within the nascent field of Quantum Mechanics. Over time it has become a foundation of Quantum Mechanics itself and the many science fiction-esque interpretations of the field. To fully appreciate the conundrum of this famously hapless cat, we will back up a few steps to learn just a little about Quantum Mechanics itself, but fear not: the main ideas are quite understandable as long as one is willing accept a bit of a blindfolded shortcut around the mathematical analysis and experimentation that accompanied them. We don't need to understand the physics itself; we just want to develop an awareness of the distinction between merely *accepting* a strange idea because experiments prove it, and really *internalizing* (or perhaps struggling to internalize) that idea. We often assume physicists do both simultaneously when a new theory is discovered, but Schrodinger illustrated otherwise. It was a challenge for even the brightest minds to really grasp the bizarre implications of their own theories, and you'll see why.

Throughout the 17th and 18th centuries, physicists had been content to divide the entire universe into two distinct categories: particles and waves. Particles are separate chunks of matter. Waves are a continuous oscillation of energy. Everything they had ever studied fell neatly into one box or the other, and each classification exhibited characteristically predictable behavior that had never been challenged. Particles are particles. Waves are waves.

Then, in the early 20th century, physicists discovered something peculiar. Particles are *not* always particles. Waves are *not* always waves. In fact, experiments began to show that these very fundamental assumptions about matter were not fundamental at all; it turns out that particles do sometimes behave like waves, and waves do in turn behave like particles, and it's *not just an act*. These distinct entities are not merely behaving like each other; rather, the *identities* of the objects themselves actually *depend on how we measure them.* For example, a beam of light measured with wave-detecting equipment will appear as a wave. That very same beam of light, when measured with particle-detecting equipment, will appear as particles. The same is true of all particles, and all waves.

What's more, we can only define that particular light beam as a particle or as a wave when we are very deliberately observing or measuring it- because our choice of measurement tool defines it. For all the moments when we are *not* observing or measuring the light, it cannot be considered a particle or a wave at all. In those moments, you might consider it neither, or both, simultaneously. Physicists define this mysterious state as **indeterminate**, and it's crucial to note they chose that word instead of *undetermined*. The object in question is not simply hidden from our knowing eyes; it actually *does not have an identity at all until we measure it.*

A dramatic pause may be appropriate here; we can certainly afford a few seconds where physicists spent two decades. Like you, they were skeptical, but they're a cautious bunch and this **wave-particle duality** was thoroughly investigated and proven very definitely true by hundreds of careful experiments (we'll spare the details here). But witnessing the outcomes of laboratory experiments does not imply a full appreciation for the *meaning* of a discovery. For physicists, the results were strange- very strange- but their confidence in the experiments and the empirical rigor of their results trumped the head scratching, "wait, what did that say?" factor. Many physicists were willing to accept the new theory *without truly understanding it*, so if you're wondering how indeterminacy can be real, you're in quite good company; the physicists had trouble with it too. Richard Feynman said, "Do not keep asking yourself, if you can possibly avoid it, 'But how can it be like that?' because you will follow it 'down the drain,' into a blind alley from which nobody has yet escaped. *Nobody knows how it can be like that.*"

Physicists initially limited their study to a manageably narrow scope of matter, the realm of super-tiny objects we call the "quantum" world: atoms and their smaller components. It may not have been an intentional avoidance of the more problematic implications at the macro-level of everyday objects, but their focus on quantum events did conveniently allow physicists to continue working with these concepts on a scale they didn't have to actually visualize. In some ways, they were practicing the physics equivalent of Chinese medicine, where theories about the internal workings of the body were supported with external observation and experimentation, but never with internal surgery or autopsy. Of course, Chinese medicine produced tomes of successful diagnosis and treatment regimens without ever mapping the internal organs or bodily systems, just as Quantum Mechanics was producing accurate experimental predictions without really *seeing* what was happening on the quantum level. And how could they see it? Chinese medicine was eventually revolutionized by the pursuit of functional anatomy as doctors began to look inside the body, but physicists had yet to really *look* at what was happening within the theories of Quantum Mechanics. That is, until rabble-rousers like Schrodinger came along. The key difference, though, is that while western medicine may have changed the way we think about the function of the body, it's still intuitively accessible. The same cannot be said for what physicists saw when Schrodinger's challenge essentially forced them to open their body of knowledge and *look.*

By 1935, Erwin Schrodinger was an accomplished physicist and major contributor to Quantum Mechanics himself. Quantum Physicists had posed the question: "Is this object a particle, or a wave?" and the answer, which everyone agreed upon, turned out to be, "It is both or neither- indeterminate- until you measure it… and then it turns out to be whatever you are measuring for.' Dissatisfied with physicists' deference to the empirical evidence without an accompanying understanding of its deeper implications, he concocted his curious experiment not to explain Quantum Physics, but to demonstrate that the existing theory suggested some highly confusing consequences, especially when physicists were forced to consider the theory as applied to 'real world' objects, scaled up from the micro-world of quantum behavior they had focused on. So Schrodinger created an example where the indeterminacy of tiny subatomic entities might hypothetically be extended into the macro-world of you and me (and cats). He suggested the following scenario:

Imagine a cat (your choice of breed, perhaps black for dramatic effect) placed in a steel box or crate, somehow secured and unable to affect his surroundings. In that same box would be a vial of poison gas attached to a device with a single atom of radioactive material included. (That atom is meant by Schrodinger to be an example everything we have here discussed; never mind the radioactivity, it's just his way of saying we have a single atom existing in an *indeterminate* state until someone measures it). We have no control over the state of the atom, only the ability to open the box and observe the situation at any given moment.

In this imaginary experiment, a device is set so that if the single atom exhibits wave behavior, the device breaks the vial and the cat is poisoned; if the atom exhibits particle behavior, the vial remains intact, along with the cat. It is assumed that, due to the completely random nature of radioactivity, *we simply cannot know* in advance whether the atom is behaving as a wave or a particle, but rather it exists in ye old indeterminate state until we open the box and observe the situation.

To the uninitiated, this problem may appear to have little to do with Quantum Mechanics. We might, in previously excusable ignorance, assume the cat simply lives on until some future time when the atom changes form and the cat is poisoned. A sad ending, but a very *definite* one, and therefore a very *false* one by Quantum rules. If we apply what we know about Quantum Mechanics to this contraption, we get a sense for where Schrodinger was headed, a strange place indeed. He was not interested in the cat's demise, but rather this conundrum: because the cat's fate is inextricably tied to the state of the atom, and if we accept (and we must) the premise that said atom has an indeterminate state prior to measurement, it must follow that the cat *also exists in a similarly indeterminate state* until the box is opened and the contents are observed (which serves as the act of measurement in this experiment).

Just as you may be willing to accept all of these ideas with a shrug and a passing thought: "that's weird... but I don't understand physics anyway," so, too, the physicists had done, but in their own way: "That's weird… but it's all subatomic particles so we can trust the math and not trouble ourselves with constructing a working model for the macro-world…" And here came Schrodinger to force them out of that comfort zone and make them attend to the implications for the 'real world.' As Schrodinger put it, "there is a difference between a shaky or out-of-focus photograph and a snapshot of clouds and fog banks." This is not a shaky, unknown mystery-in-box, this is a very real, very cloud-like cat who is both alive and dead (indeterminate) until the box is opened.

If you're thinking this is absurd, you're still in good company. At the time, the majority of physicists agreed. Schrodinger essentially challenged the entire physics community to concede that, because the act of measurement itself determines the state of some objects, like atoms, it must also extend to larger objects, like cats. It was easy for physicists to accept quantum behavior on the level of subatomic particles because they reside in a microscopic world we are rarely forced to visualize; but we are not afforded that luxury of blindness in the larger tangible world we interact with.

Of course, this was not a happy concession, or one that resulted in greater knowledge for the world of physics. It was not a clarification. It was a challenge to physicists; it was the forceful removal of blinders that had previously provided a conveniently narrow scope to reveal just how odd and problematic the full, large-scale interpretations of Quantum Mechanics would prove to be. As a thought experiment, it offered no mathematical analysis or empirical evidence, (which physicists have enshrined as the only source for *real* knowledge); instead it illuminated the dangerous rift that opens up between math and intuitive reality when they trust the former to the exclusion of the latter, and it encouraged physicists to attend to that rift. Indeterminacy is counter intuitive on a small scale, and proportionally more confusing on a larger scale. Schrodinger's thought experiment was not an act of punctuation at the conclusion of a new discovery, but rather a gauntlet thrown down to ask the physicists of the day: "How will you reconcile this quantum absurdity with the real world?" And they set about the task of answering that call. They continue, only partially successful, to this day.

Most people, physicists and non-physicists alike, naturally seek an easy 'solution' to this thought experiment, (or at least a resolution to the unsettled feeling it surely arouses), but as with some of life's more significant questions, the answer may not exist in a neat form. Schrodinger himself did not suggest any reconciliation between Quantum Mechanics and its peculiar implications. It turns out that, even if some cruel physicist wished to attempt this experiment, it would be nearly impossible to carry out due to the limitations of space and matter and vial-breaking-devices. However, real experiments *have* been performed, not on cats, but on electrons, and increasingly 'larger' objects. First those electrons, then whole atoms, and most recently, molecules 100 times bigger than atoms, have all been confirmed to exist in an indeterminate state prior to measurement. It would seem Schrodinger's point is made: indeterminacy extends into the 'real world,' as hard as it is for us to imagine, and we'd better think about that. Physicists have not only *accepted* what the experiments confirm about Quantum Mechanics, but are beginning to *internalize* its consequences with realities that are closer and closer to our own.

Physicists have since begun offering possible 'interpretations' of Quantum Mechanics that seek to do just what they were challenged to do: reconcile its strange implications with the more familiar and intuitive models of physics behavior we have long understood. Of course, we have not arrived at a universally accepted interpretation just yet, and the interpretations themselves often introduce more paradoxes of their own. As these interpretations of Quantum Mechanics are developed, refined, and sometimes rejected, though, they are often classified based on how they would answer to or explain this now-classic thought experiment and it's illustration of the problems with indeterminacy. Physicists have even taken to calling this indeterminate state a 'cat state' in deference to the thought experiment that first challenged, and then motivated, an entire community of scientists and philosophers alike.

It would seem the more certain we become about the laws of nature, the less certain we become about our own existence.