ALSO BY AMIT GOSWAMI

*The Concepts of Physics*
*Quantum Mechanics*

With Maggie Goswami

*The Cosmic Dancers*

# THE SELF-AWARE UNIVERSE

## HOW CONSCIOUSNESS CREATES THE MATERIAL WORLD


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# Chapter 6

# THE NINE LIVES OF SCHRÖDINGER'S CAT

MANY OF THE FOUNDERS of quantum physics had a hard time accepting its strange consequences. Schrödinger himself expressed his reservations about the probability-wave interpretation of quantum mechanics in the paradox now known as Schrödinger's cat.

Suppose that we put a cat in a cage with a radioactive atom and a Geiger counter. The radioactive atom will decay in accordance with probabilistic rules. If the atom decays, the Geiger counter will tick, the ticking will trigger a hammer, the hammer will break a bottle of poison, and the poison will kill the cat. Let us suppose that there is a 50 percent chance of this occurring within an hour (fig. 21).

How, then, would quantum mechanics describe the state of the cat after an hour? Of course, if we look, we will find the cat to be either alive or dead. What if we do not look? The probability that the cat is dead is 50 percent. The probability that the cat is alive is also 50 percent.

If you think classically, in the manner of the material realists, and take determinism and causal continuity as your guiding principles, then you might make a mental analogy to the situation in which someone has flipped a coin and then has hidden it under his palm. You do not know whether the outcome is heads or tails, but of course, it is one or the other. The cat is either dead or alive, with a 50 percent chance for each outcome. You just do not know which



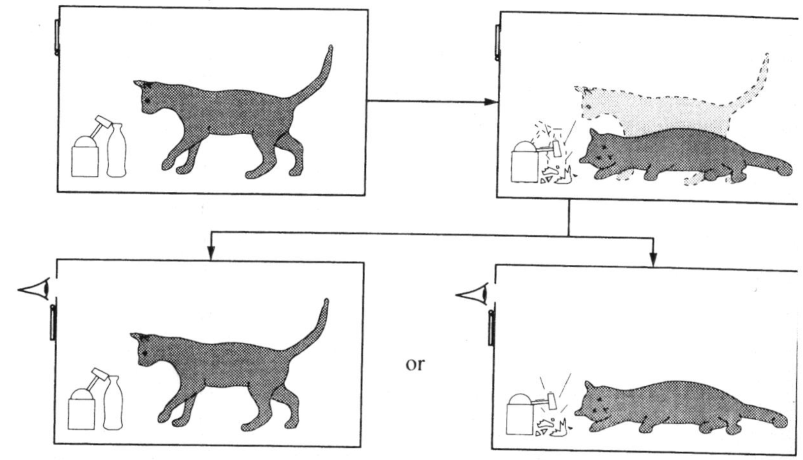


*Figure 21.* The paradox of Schrödinger's cat. After an hour with a radioactive atom in a cage, the cat becomes a coherent superposition of a half-dead and half-alive cat. Observation always reveals either a dead cat or a live cat. (Reprinted from A. Goswami, *Quantum Mechanics*; permission granted by Wm. C. Brown, Inc., publisher.)

outcome has, in fact, been realized. This scenario is not what the mathematics of quantum mechanics portrays. Quantum mechanics deals with probabilities very differently. It describes the state of the cat at the end of the hour as half alive and half dead. Inside the box is, quite literally, "a coherent superposition of a half-alive and a half-dead cat," to use the proper jargon. The paradox of a cat that is dead and alive at the same time is a consequence of the way in which we do our calculations in quantum mechanics. However bizarre its consequences, we must take this mathematics seriously because the same mathematics gives us the marvels of transistors and lasers.

The following parody of T. S. Eliot's *Old Possum's Book of Practical Cats* summarizes this absurd situation:

Schrödinger's cat's a mystery cat,
he illustrates the laws;
the complicated things he does
have no apparent cause;
he baffles the determinist,
and drives him to despair
for when they try to pin him down—
*the quantum cat's not there!*[1]

The parody is right, of course. Nobody has actually seen a quantum cat, or a coherent superposition—not even a quantum physicist. Indeed, if we look into the cage, the cat is found to be either alive or dead. The inevitable question arises: What's so special about our making an observation that it can resolve the cat's diabolical dilemma?

It is one thing to talk glibly about an electron passing through two slits at the same time, but when we talk of a cat being half dead and half alive, the preposterousness of the quantum coherent superposition hits home.

One way to get out of the predicament is to insist that the mathematical prediction of the coherent superposition must not be taken literally. Instead, we can pretend, following the statistical-ensemble interpretation favored by some materialists that quantum mechanics makes predictions only about experiments involving a very large number of objects. If there were ten billion cats, all in individual cages set up identically, quantum mechanics would tell us that half of them would be dead in an hour, and surely observation would bear out the truth of that assertion. Maybe for a single cat the theory just does not apply. In the last chapter a similar argument was made for electrons. It is a fact, however, that the ensemble interpretation encounters difficulty explaining even the simple double-slit interference pattern.[2]

Furthermore, the ensemble interpretation is tantamount to giving up quantum mechanics as a physical theory for the description of a single object or of a single event. Since single events do occur (even single electrons have been isolated), we must be able to talk about single quantum objects. Indeed, quantum mechanics was formulated to apply to single objects, notwithstanding the paradoxes that it raises by doing so. We must face up to Schrödinger's paradox and seek a way to resolve it. The alternative is to have no physics at all for single objects—a wholly undesirable alternative.

Many physicists today hide behind the anti-metaphysical philosophy of logical positivism when dealing with the paradox of Schrödinger's cat. Logical positivism is the philosophy that grew out of the Viennese philosopher Ludwig Wittgenstein's *Tractatus Logico-Philosophicus*, a work in which he argued, famously, that "Whereof one cannot speak, thereof one must remain silent." Following this dictum, these physicists—we may call them neo-Copenhagenists—maintain that we should confine our discussion of reality to what is seen instead of trying to assert the reality of something that we cannot observe. For them, the point is that we never see the coherent superposition. Is the unobserved cat half-dead and half-alive? You cannot ask that question, they would say, because it cannot be answered. This, of course, is sophistry. A question that cannot be answered directly can nonetheless be approached circuitously, and its answer can be calculated on the grounds of consistency with what we can directly know. Moreover, avoiding metaphysical questions entirely is not consistent with the spirit of the original Copenhagen interpretation and the way in which Bohr and Heisenberg saw things.



The Copenhagen interpretation, if one follows Bohr, lessens the absurdity of the half-dead, half-alive cat by means of the complementarity principle: The coherent superposition is an abstraction; as an abstraction, the cat is able to exist as both live and dead. This is a complementary description, complementary to the dead or alive description that we give when we do see the cat. According to Heisenberg, the coherent superposition—the half-dead, half-alive cat—exists in transcendent potentia. It is our observation that collapses the cat's dichotomous state into a single one.

What sense are we to make of this notion of a half-dead, half-alive cat existing in potentia? An answer that sounds like science fiction has come from the physicists Hugh Everett and John Wheeler.[3] According to Everett and Wheeler, both possibilities, live cat and dead cat, occur—but in different realities, or parallel universes. For every live cat we find in the cage, prototypes of us in a parallel universe open a prototype cage only to discover a prototype cat that is dead. An observation of the cat's dichotomous state forces the universe itself to split into parallel branches. This is an intriguing idea, and some science fiction writers (notably Philip K. Dick) make good use of it. Unfortunately, this is also a costly idea. It would double the amount of matter and energy each time an observation forces the universe to bifurcate. It offends our taste for parsimony, which may be a prejudice but is nonetheless a cornerstone of scientific reasoning. Furthermore, since the parallel universes do not interact, this interpretation is difficult to put to experimental test and therefore not useful from a scientific point of view. (Fiction is more tractable. In Philip Dick's *The Man in the High Castle*, the parallel universes do interact. How else would there be a story?)

Fortunately, an idealist resolution presents itself: Since our observation magically resolves the dichotomy of the cat, it must be us—our consciousness—that collapses the cat's wave function. Material realists do not like this idea, because it makes consciousness an independent, causal entity; admitting that would be like putting nails in the coffin of material realism. Materialism notwithstanding, such luminaries as John von Neumann, Fritz London, Edmond Bauer, and Eugene Paul Wigner have endorsed this resolution to the paradox.[4]

## THE IDEALIST RESOLUTION

In the idealist resolution, it is observation by a conscious mind that resolves the alive-or-dead dichotomy. Like Platonic archetypes, coherent superpositions exist in the never-never land of a transcendent order until we collapse them, bringing them into the world of manifestation with an act of observation. In the process, we choose one facet out of two, or many, that are permitted by the Schrödinger equation; it is a limited choice, to be sure, subject to the overall probability constraint of quantum mathematics, but it is a choice nevertheless.

Even if material realism is false, should we hastily give up scientific objectivity and invite consciousness into our science? Paul Dirac, one of the pioneers of quantum physics, once said that great breakthroughs in physics always involve giving up some great prejudice. Perhaps the time has come to give up the prejudice of strong objectivity. Bernard d'Espagnat suggests that the objectivity permitted by quantum mechanics is weak objectivity.[5] Instead of the observer-independence of events demanded by strong objectivity, quantum mechanics allows a certain meddling by the observer—but in such a way that the interpretation of the events does not depend on any particular observer. Thus weak objectivity is observer-invariance of events: Irrespective of who the observer is, the event remains the same. In view of the subjective choice involved in individual measurements, it is a statistical principle to be sure, and observer invariance holds only for a large number of observations, which is nothing new. Having long accepted the probability interpretation of quantum mechanics, we are already committed to accepting the statistical nature of some of our scientific principles: the causality principle, for example. As cognitive psychology routinely demonstrates, we can certainly do science with weak objectivity defined in this way. We do not really need strong objectivity.

The consciousness resolution of Schrödinger's paradox is the



most straightforward one—so much so that it is sometimes referre to as the naive resolution. Many questions have been raised abou this resolution, however, and only by answering these questions ca we overcome the accusation of naiveté.

## QUESTIONS ABOUT THE IDEALIST RESOLUTION

One question you may still be asking is, How can a cat be half-dea and half-alive? It cannot, if you are thinking as a material realist The material realist must assume that the state of the cat at ever moment is either this or that, dead or alive, in a causally continuou fashion. Materialist thinking, however, is the result of assumption of causal continuity and an either/or description of events. Thes assumptions are not necessarily true, especially when they ar tested against quantum mechanical experiments.

To an idealist philosopher the paradox of a cat being both dea and alive is not particularly disturbing. In a Zen story, a master wa shown a so-called dead man whose funeral was being prepared When he was asked if the man was dead or alive, the Zen maste replied, "I cannot say." How could he? According to idealism, th essence of a man, consciousness, never dies. So it would be incorrec to say outright that the man is dead. When a man's body is being prepared for his funeral, however, it would be ridiculous to say tha the man is alive.

Is the cat dead or alive? Zen master Joshu answered the question Does a dog have Buddha nature? by replying, "mu" (pronounced moo). Again, to say no would be wrong since all creatures, according to Buddha's teaching, have Buddha nature. To say yes would also be tricky because the Buddha nature is to be realized and lived—not a matter of intellectual truth. So the answer is mu: neither yes nor no.

Quantum mechanics seems to imply an idealist philosophy like that of the Zen masters when it asserts that Schrödinger's cat is, at the end of an hour, half dead and half alive. How can this be? How can consciousness be decisive in shaping the reality of the physical world? Does this not imply the primacy of consciousness over matter?

If Schrödinger's cat is both alive and dead before we look inside the box but has a unique state (alive or dead) after we look, then we must be doing something just by looking. How can a tiny peek have an effect on the physical state of a cat? These are questions that realists ask when trying to refute the idea that the coherent superposition is collapsed by consciousness.

Yes, the idealist resolution does imply the action of consciousness upon matter. That action, however, poses a problem only for material realism. In this philosophy, consciousness is an epiphenomenon of matter, and it seems impossible that an epiphenomenon of matter could act on the very fabric of which it is built—in effect causing itself. That causal paradox is avoided by monistic idealism, in which consciousness is primary. In consciousness, coherent superpositions are transcendent objects. They are brought into immanence only when consciousness, by the process of observation, chooses one of the many facets of the coherent superposition, though its choice is constrained by the probabilities allowed by the quantum calculus. (Consciousness is lawful. The creativity of the cosmos comes from the creativity of its quantum laws, not from arbitrary lawlessness.)

According to monistic idealism, objects are already in consciousness as primordial, transcendent, archetypal possibility forms. The collapse consists not of doing something to objects via observing but of choosing and of recognizing the result of that choice.

Look back once more at the gestalt illustration "My Wife and My Mother-in-Law" (fig. 12). In this illustration, two pictures are superimposed. When we see the wife (or the mother-in-law), we are not doing anything to the picture. We are simply choosing and recognizing our choice. The process of collapse by consciousness is something like this.

There are, however, dualists who try to explain the action of consciousness in Schrödinger's paradox by finding evidence of psychokinesis: the ability to move matter with the mind.[6] Eugene Paul Wigner argues that if a quantum object can affect our consciousness, then our consciousness must be able to affect a quantum object. The evidence for psychokinesis, however, is scanty and dubious. Furthermore, evidence from another paradox—that of Wigner's friend—effectively rules out a dualistic interpretation.

## THE PARADOX OF WIGNER'S FRIEND

Suppose that two people simultaneously open the cage of the cat. If the observer chooses the outcome of collapse, as idealism seems to



imply, then suppose the two observers chose differently, would that not create a problem? If we say no, only one of the observers gets to choose, the realist is not satisfied and rightly so.

The paradox of Wigner's friend, formulated by physicist Eugene Wigner, goes something like this: Suppose that instead of observing the cat himself, Wigner asks a friend to do so. His friend opens the cage, sees the cat, and then reports the results of his observation to Wigner. At this point, we can say that Wigner has just actualized the reality that includes his friend and the cat. There is a paradox here: Was the cat alive or dead when Wigner's friend observed it but before he reported the observation? To say that the state of the cat did not collapse when his friend observed the cat is to maintain that his friend remained in a state of suspended animation until Wigner asked him—that his friend's consciousness could not decide whether the cat was alive or dead without Wigner's prodding. That sounds a lot like solipsism—the philosophy that posits you as the only conscious being with everybody else imaginary. Why should Wigner be the privileged one who gets to collapse the cat's state function?

Suppose we say, instead, that Wigner's friend's consciousness collapses the superposition. Does that not open up a hornet's nest? If Wigner and his friend look at the cat simultaneously, whose choice is going to count? What if the two observers choose differently? The world would be pandemonium if individual people were to decide the behavior of the objective world, because we know subjective impressions are often contradictory. The situation in such a case would be like that of people coming from different directions and choosing the color (red or green) of a traffic light at will. This argument is often regarded as a fatal blow against the consciousness resolution of Schrödinger's paradox. It is fatal, however, only to a dualist interpretation. Let us explore Wigner's paradox in more detail to see why this is so.

Wigner has compared his paradoxical state of affairs with one in which an inanimate apparatus is used to make the observation. When a machine is used, there is no paradox. There is nothing paradoxical or upsetting about a machine being in limbo for a while, but experience says that there is something decisive about a conscious being's observation. As soon as a conscious being observes, the material reality becomes manifest in a unique state. Says Wigner:

> It follows that the being with a consciousness must have a different role in quantum mechanics than the inanimate measuring device. . . . This argument implies that 'my friend' has the same types of impressions and sensations as I—in particular, that, after interacting with the object, he is not in that state of suspended animation. . . . It is not necessary to see a contradiction here from the point of view of orthodox quantum mechanics, and there is none if we believe that the alternative is meaningless, whether my friend's consciousness contains . . . the impression of having seen [either a dead cat or a live cat]. However, to deny the existence of the consciousness of a friend to this extent is surely an unnatural attitude, approaching solipsism, and few people in their heart will go along with it.[7]

The paradox is subtle, but Wigner is right. We do not have to say that until Wigner manifests his friend, his friend stays in a state of suspended animation. Nor do we have to resort to solipsism. There is an alternative.

Wigner's paradox arises only when he makes the unwarranted dualist assumption that his consciousness is separate from his friend's. The paradox disappears if there is only one subject, not separate subjects as we normally understand them. The alternative to solipsism is a unitive subject-consciousness.

When I observe, what I see is the whole world of manifestation, but this is not solipsism, because there is no individual I that sees as opposed to other I's. Erwin Schrödinger was right when he said: "Consciousness is a singular for which there is no plural." Etymology and orthography have preserved the singularity of consciousness. The existence in language of such terms as *I* and *my*, however, leads us into a dualistic trap. We think of ourselves as separate because we speak of ourselves in that way.

Similarly, people fall into thinking about having consciousness, as in the question, Does a cat have consciousness? It is only in material realism that consciousness is something merely to be possessed. Such a consciousness would be determined, not free, and would not be worth having.

## The Watched Pot Does Boil

Consider another wrinkle in Schrödinger's paradox. Suppose that Schrödinger's cat is itself a conscious being. The concept becomes



even more acute by assuming a human being inside the cage with the radioactive atom, the bottle of poison, and all the rest. Suppose then, that we open the cage after an hour and, if he is still alive, ask him if he experienced a half-alive, half-dead state? Nope! he will say. Are we getting into trouble here for the idealist interpretation? Consider for a moment. What if we ask him, instead, whether he experienced being alive all the time. After some reflection, if ours is a reflective subject, he will probably say no. You see, we are not conscious of our bodies all the time. In fact, we have very little consciousness of our bodies under ordinary circumstances. So here is what the idealist interpretation may describe as happening. During the hour, every now and then, he was conscious that he was alive. In other words, he regarded himself. At those times his wave function collapsed, and fortunately the choice was the alive state each time. In between these moments of wave collapse his wave function expanded and became a coherent superposition of dead and alive in the transcendent domain that is beyond experience.

You know how we see a motion picture. Our brain-mind cannot discern the individual still pictures that race before our eyes at a speed of twenty-four frames per second. Similarly, what seems to be continuity to a human observer watching himself is really a mirage consisting of many discontinuous collapses.

This last argument also means that we cannot save Schrödinger's cat from the diabolical result of the decay of the radioactive atom by constantly looking at it, and thus somehow collapsing its wave function continuously and keeping it alive. It is a noble thought, but it will not work—for the same reason that a watched pot boils, even though the adage suggests otherwise. It is a good thing, too, that the watched pot boils, because if we could prevent change just by staring at an object, the world would be full of narcissists trying to escape aging and death by meditating on themselves.

Heed Erwin Schrödinger's reminder: "Observations are to be regarded as discrete, discontinuous events. Between there are gaps which we cannot fill in."

The resolution of the Schrödinger's cat paradox tells us a great deal about the nature of consciousness. It chooses among alternatives when it manifests the material reality; it is transcendent and unitive; and its doings elude our normal mundane perception. Admittedly, none of these aspects of consciousness is self-evident to common sense. Try to suspend your disbelief and remember what Robert Oppenheimer once said: "Science is uncommon sense."

Quantum collapse is a process of choosing and recognizing by a conscious observer; there is ultimately only one observer. This means that we have one other classic paradox to resolve.

## WHEN IS A MEASUREMENT COMPLETE?

To some realists a measurement is complete when a classical measuring apparatus, such as the Geiger counter in Schrödinger's cat cage, measures a quantum object; it is complete when the counter ticks. Note that if we accept such a solution, the paradox of the cat's dichotomous state does not arise.

This reminds me of a story. Two elderly gentlemen were talking, and one was complaining about his chronic gout. The other said with some pride: "I never have to worry about gout; I take a cold shower every morning." The gentleman with gout looked at him quizzically and replied: "So you got chronic cold shower instead!"

These realists try to replace the dichotomy of Schrödinger's cat with another: a classical-quantum dichotomy. They divide up the world into quantum objects and their classical measurement apparatuses. Such a dichotomy, however, cannot be upheld; neither is it needed. We can assert that all objects obey quantum physics (the unity of physics!) and yet answer satisfactorily the question, When is a measurement complete?

What defines a measurement? Put slightly differently, when can we say that a quantum measurement is completed? We can approach the answer historically.

Werner Heisenberg, who proposed the uncertainty principle, formulated a thought experiment that Bohr clarified further. Recently David Bohm has given an account of the experiment, and I will adapt it here.[8] Suppose a particle is at rest in the target plane of a microscope and that we are analyzing its observation in terms of classical physics. To observe the target particle, we focus (with the help of the microscope) another particle that is deflected by the target particle onto a photographic emulsion plate, leaving a track. Based on the track and on our knowledge of how the microscope works, we can determine, according to classical physics, both the position of the target particle and the momentum imparted to it at the moment of deflection. The specific experimental conditions do not influence the final result.



All this changes in quantum mechanics. If the target particle is an atom and if we are looking at it through an electron microscope in which an electron is deflected from the atom onto a photographic plate (fig. 22), the following four considerations enter:

1. The deflected electron must be described as both a wave (while it is traveling from the object $O$ to the image $P$) and as a particle (at arrival at $P$ and while leaving the track $T$).
2. Because of this wave aspect of the electron, the image point $P$ tells us only the probability distribution of the position of the object $O$. In other words, the position is determined only within a certain uncertainty $\Delta x$ (pronounced delta ex).
3. Similarly, argued Heisenberg, the direction of the track $T$ gives us only the probability distribution of the momentum of $O$ and thus determines the momentum only within an uncertainty $\Delta p$ (Delta pee). Using simple mathematics, Heisenberg was able to show that the product of the two uncertainties is equal to or greater than Planck's constant. This is Heisenberg's uncertainty principle.
4. In a more detailed mathematical account, Bohr pointed out that it is impossible to specify the wave function of the observed atom separately from that of the electron that is used to see it. In truth, said Bohr, the wave function of the electron cannot be unentangled from that of the photographic emulsion. And so on. We cannot draw the line in this chain without ambiguity.

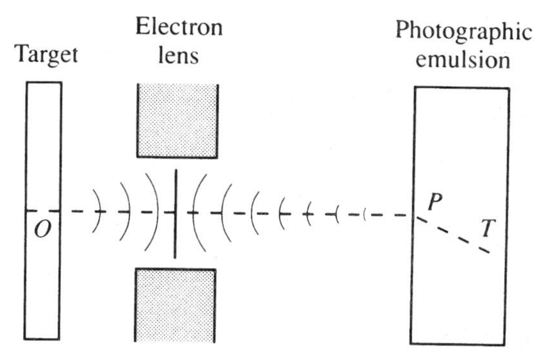


*Figure 22.* The Bohr-Heisenberg microscope. (Reprinted with permission from J. A. Schumacher.)

In spite of the ambiguity in drawing the line, Bohr felt that we must draw it because of the "indispensable use of classical concepts in the interpretation of all proper measurements." The experimental arrangement, said Bohr reluctantly, must be described in totally classical terms. The dichotomy of quantum waves must be assumed to terminate with the measuring apparatus.[9] As was pointed out cogently by the philosopher John Schumacher, however, all actual experiments have a second Heisenberg microscope built into them:[10] The process of seeing the emulsion track involves the same kind of consideration that led Heisenberg to the uncertainty principle (fig. 23). Photons from the emulsion track are amplified by an experimenter's own visual apparatus. Can we ignore the quantum mechanics of our own seeing? If not, is our brain-mind-consciousness not inexorably connected with the measurement process?

## IS THE CAT QUANTUM OR CLASSICAL?

When you think about it, it becomes clear that Bohr was replacing one dichotomy, that of the cat, with another, that of a world divided into quantum and classical systems. According to Bohr, we cannot separate the wave function of the atom from the rest of the environment in the cat's cage (the various measuring devices for the atom's decay, such as the Geiger counter, the poison bottle, and even the cat), and the line we draw between the micro world and the macro world is quite arbitrary. Unfortunately, Bohr also maintained that we must accept that the observation by a machine—a measuring apparatus—resolves the dichotomy of a quantum wave function.

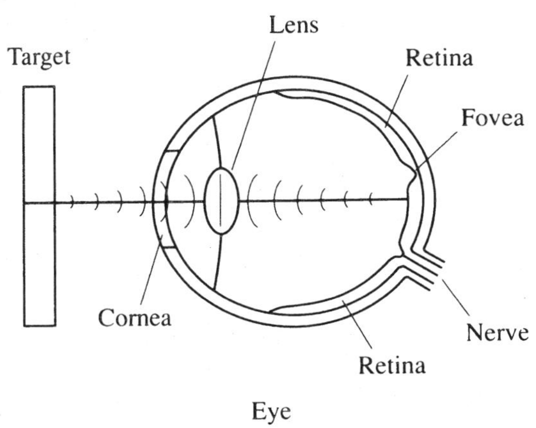


*Figure 23.* The mechanics of seeing. Another Heisenberg microscope in operation? (Reprinted with permission from J. A. Schumacher.)



Any macro body (the cat or any observing machine), however, is ultimately a quantum object; there is no such thing as a classical body unless we are willing to admit a vicious quantum/classical dichotomy in physics. It is true that a macro body's behavior can be predicted in most situations from the rules of classical mechanics. (Quantum mechanics gives the same mathematical predictions as does classical mechanics in such cases—this is the correspondence principle that Bohr himself pioneered.) For this reason we often loosely refer to macro bodies as being classical. The measurement process, however, is not such a case, and the correspondence principle does not apply to it. Bohr knew this, of course. In his celebrated debates with Einstein, he often invoked quantum mechanics for describing macro bodies of measurement in order to refute the acute objections that Einstein raised to probability waves and to the uncertainty principle.[11]

As an example of the debate between Bohr and Einstein, consider the double-slit arrangement but include an additional facet. Suppose that before their incidence on the double slit, the electrons pass through a single slit in a diaphragm—its purpose being the accurate definition of the starting point of the electrons. Einstein suggested that this initial slit be mounted on some extremely light springs (fig. 24). Einstein argued that if the first slit deflects an electron to the upper of the two slits, then the first diaphragm will recoil downward from the principle of conservation of momentum. The opposite would happen if an electron is deflected downward, toward the bottom slit. Thus the measurement of the recoil of the diaphragm will tell us which slit the electron really passes through, information that quantum mechanics is supposed to deny. If the first diaphragm is really classical, then Einstein is right. Defending quantum mechanics, Bohr pointed out that ultimately the diaphragm also obeys quantum uncertainty. Thus if its momentum is measured, its position becomes uncertain. This broadening of the first slit effectively wipes out the interference pattern, as Bohr was able to demonstrate.

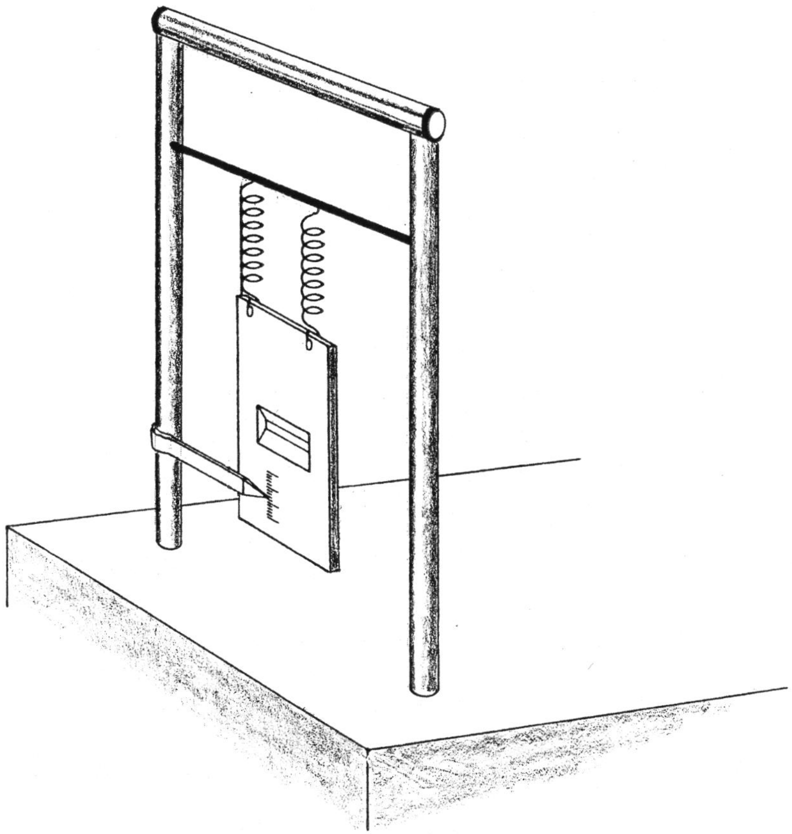

*Figure 24.* Einstein's spring-mounted initial slit for the double-slit experiment. If electrons go through a slit mounted on springs, as shown, before going through the double-slitted screen (not shown), is it possible to tell which slit an electron goes through without destroying the interference pattern?

Suppose further, however, that a complementarity principle is operating and that sometimes a macro apparatus does take on the quantum dichotomy (as shown by the Bohr-Einstein debate), but that at other times it does not—as happens with a measuring apparatus. This idea, called macrorealism, is ingenious, and it comes from the brilliant physicist Tony Leggett, whose work has inspired a beautiful experimental device called SQUID (Superconducting Quantum Interference Device).[12]



Ordinary conductors conduct electricity, but they always offe some resistance to the flow of electric current through them, whicl results in a loss of electrical energy as heat. In contrast, supercon ductors allow a current to flow without resistance. Once you set up ; current through a superconducting loop, the current will flow, prac tically forever—even without a source of power. Superconductivit is due to a special correlation between electrons that extends ove the whole body of the superconductor. It takes energy for the elec trons to break away from this correlated state, thus the state i relatively immune to the random thermal motion present in aı ordinary conductor.

The SQUID is a piece of superconductor with two holes in it tha very nearly touch at a point called the weak link (fig. 25). Suppos we set up a current in the loop around one of the holes. A curren sets up a magnetic field just as any electromagnet does, and the fiel lines representing the magnetic field pass through the hole—that too, is usual. What is unusual for a superconductor is that th magnetic flux, the number of field lines per unit area, is quantized

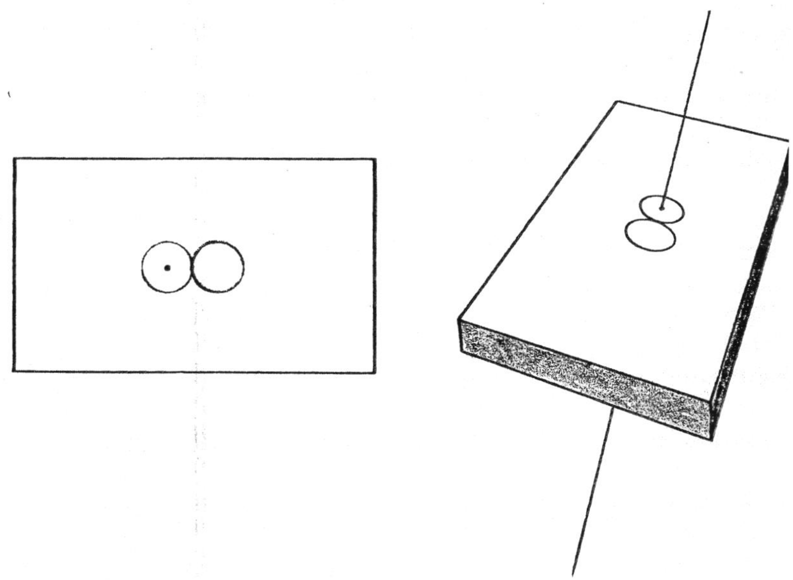

*Figure 25.* Will the line of flux be shared between the two holes, revealin quantum interference at the macro level?

the magnetic flux passing through the hole is discrete. This gave Leggett his key idea.

Suppose we set up such a small current that there is only one quantum of flux. Then we have created a double slit-type interference question. If there is only one hole, then obviously the flux quantum can be anywhere in it. If the link between the two holes is too thick, then the flux will be localized in only one hole. With just the right size of weak link, might we set up quantum interference such that the flux quantum is in both holes at the same time, nonlocalized? If so, quantum coherent superpositions clearly persist even at the scale of macrobodies. If no such nonlocalization is seen, then we may be able to conclude that macrobodies really are classical and do not permit coherent superpositions as their allowed states.

So far, there is no evidence of any breakdown of quantum mechanics with SQUID, but Leggett strongly expects quantum theory to break down. Said he at a recent conference: "But occasionally at night, when the full moon is bright, I do what in the physics community is the intellectual equivalent of turning into a werewolf: I question whether quantum mechanics is the complete and ultimate truth about the physical universe. . . . I am inclined to believe that at *some* point between the atom and the human brain it [quantum mechanics] not only may but *must* break down."[13]

Spoken like a true material realist!

Many physicists feel inclined to ask the same questions that inspire Leggett, so the research with SQUID continues. I suspect that one of these days it will turn up evidence in favor of quantum mechanics and will show that quantum coherent superpositions are demonstrably present even in macrobodies.

If we do not deny that all objects ultimately pick up quantum dichotomy, then, as von Neumann first argued, if a chain of material machines measures a quantum object in a coherent superposition, they all in turn pick up the dichotomy of the object, ad infinitum (fig. 26).[14] How do we get out of the logjam that the von Neumann chain creates? The answer is startling. *By jumping out of the system, out of the material order of reality.*

We know that an observation by a conscious observer ends the dichotomy. It should be obvious, therefore, that consciousness must work from outside the material world; in other words, consciousness must be transcendent—nonlocal.



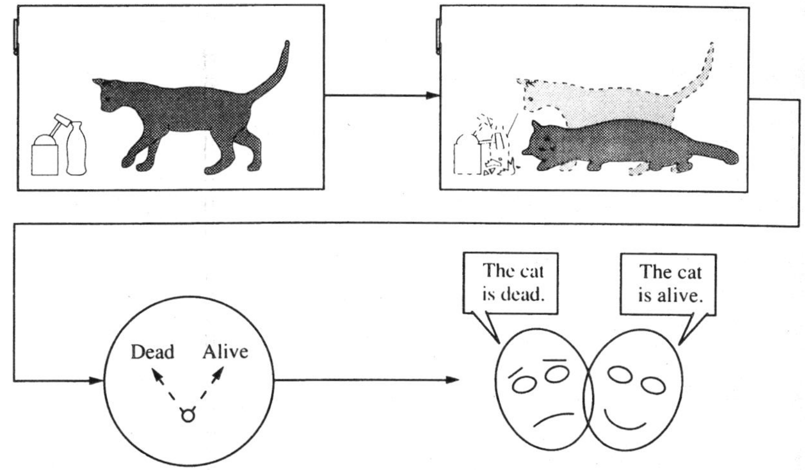


*Figure 26.* The von Neumann chain. Following von Neumann's argument, even our brain-mind catches the dichotomy of the cat, so how does the chain terminate? (Reprinted from A. Goswami, *Quantum Mechanics*; permission granted by Wm. C. Brown, Inc., publisher.)

## RAMACHANDRAN'S PARADOX

If it still bothers you that consciousness is transcendent, you may enjoy examining a paradox that was constructed by the neurophysiologist V. S. Ramachandran.[15]

Suppose that with some supertechnology it is possible to record with microelectrodes, or some such thing, everything that happens in the brain when bombarded by an external stimulus. From such data plus some supermathematics, you can imagine coming up with a complete and detailed state description of the brain under the given stimulus.

Suppose the stimulus is a red flower and that you show it to several people, collect the data, analyze it, and come up with a set of brain states that corresponds to the perception of a red flower. You would expect that, except for minor statistical fluctuations, you would come up with essentially the same state description (something like, certain brain cells in a certain area of the brain involved in color perception have responded) each time.

You might even imagine that with the aid of supertechnology you record and analyze the data of your own brain (upon seeing the red flower). The brain state you find for yourself should not have any discernible difference from all the others.

Consider the following curious twist to the experiment: You have no reason to suspect that the description of all the other people's brain states is not complete (especially if your belief in your superscience is complete). And yet, with regard to your own brain state, you know that something is left out: namely, your role as the observer—your consciousness of the experience represented by your brain state, the actual conscious perception of redness. Your subjective experience could not be part of the objective brain state because in such a situation, who would be observing the brain? The famous Canadian neurosurgeon Wilder Penfield similarly was bewildered by pondering the prospect of performing brain surgery on himself: "Where is the subject and where is the object if you are operating on your own brain?"[16]

There must be a difference between your brain as the observer and the brains of those whom you observe. The only alternative conclusion is that the brain states that you constructed even with superscience are incomplete. Since your brain state is incomplete and other people's brain states are identical to yours, then they must also be incomplete, for they all leave out consciousness.

This is a paradox for the material realists because, from their viewpoint, neither of the above outcomes is desirable. The materialist will be reluctant to give a special privilege to a particular observer (that would amount to solipsism) yet also averse to admitting that any achievable description of the brain state using materialistic science would be, ipso facto, incomplete.

The paradox is resolved by the idealist interpretation of quantum mechanics because in that interpretation the quantum-mechanical description of the brain-mind does not include the transcendent subject, consciousness, and is admitted to be incomplete to that extent. In that incompleteness, room is made for conscious experience.

An important key is the neurosurgeon's question, Where is the subject and where is the object if you are operating on your own brain? The point is made by the expression "what we are looking for is what is looking." Consciousness involves a paradoxical self-reference, an ability, taken for granted, to refer to ourselves separate from the environment.



Erwin Schrödinger said: "Without being aware of it and without being rigorously systematic about it, we exclude the Subject of Cognizance from the domain of nature that we endeavor to understand."[17] A quantum measurement theory that dares to invoke consciousness in the affairs of quantum objects, in order to be "rigorously systematic," must deal with the paradox of self-reference. Let us elaborate on this concept.

### WHEN IS A MEASUREMENT COMPLETE? [REPRISE]

A subtle criticism can be made of the assertion that a transcendent consciousness collapses the wave function of a quantum object. The criticism is that the consciousness that causes the collapse of the wave function might be that of an external, omnipresent God, as in the following:

> There once was a man who said, "God
> Must think it exceedingly odd
> If he finds that this tree
> Continues to be
> When there is no one about in the quad."
>
> Dear sir, your astonishment's odd
> I am always about in the quad
> And that's why the tree
> Will continue to be
> Since observed by, Yours faithfully, God.[18]

An omnipresent God collapsing the wave function does not resolve the measurement paradox, however, because we can ask, At what point is the measurement complete if God is always looking? The answer is crucial: *The measurement is not complete without the inclusion of the immanent awareness.* The most familiar example of an immanent awareness is, of course, that of a human being's brain-mind.

When is a measurement complete? When the transcendent consciousness collapses the wave function by means of an immanent brain-mind looking on with awareness. This formulation agrees with our commonsense observation that there is never an experience of a material object without a concomitant mental object, such as the thought I see this object, or without, at least, awareness.

Note that we have to make a distinction between consciousness with awareness and without awareness. The collapse of the wave function takes place in the former case but not in the latter. Consciousness without awareness is referred to as unconscious in the psychological literature.

Of course, there is some causal circularity to the view that immanent awareness is needed to complete the measurement, since without the completion of the measurement there can be no immanent awareness. Awareness or measurement, which comes first? Which is the first cause? Are we stuck with a chicken-or-the-egg question?

A Sufi story has a similar flavor. One night the Mulla Nasruddin was traveling a lonely road when he spotted a troop of horsemen approaching. The Mulla became nervous and started to run. The horsemen saw him running and went after him. Now the Mulla became really fearful. Coming on the walls of a graveyard and propelled by fear, he jumped the wall, found an empty coffin, and lay down in it. The horsemen had seen him jump the wall, and they followed him into the graveyard. After a little search they found the Mulla looking fearfully up at them.

"Is there anything wrong?" the horsemen asked the Mulla. "Can we help you in any way? Why are you here?"

"Well, it's a long story," replied the Mulla. "To make it short, I am here because of you, and I can see that you are here because of me."

If we are stuck with only one order of reality, the physical order of things, then there is a genuine paradox here for which there is no solution within material realism. John Wheeler has called the circularity of quantum measurement a "meaning circuit,"[19] which is a very sensitive description, but the real question is, Who reads the meaning? Only for idealism is this no paradox, because consciousness acts from outside the system and completes the meaning circuit.

This solution is similar to that of the so-called prisoner's problem, an elementary problem of game theory.[20] Through a tunnel dug with the help of an outside friend, you plan to escape from a prison cell (fig. 27). Obviously, your escape will be much facilitated if both you and your friend dig from opposite sides of the same corner; communication is not possible, however, and there are six corners from which to choose. The chance of escape does not look good, does it? But consider for a moment the shape of your cell, and the chance is excellent that you will choose to dig at corner number 3. Why? Because number 3 is the only corner that looks different (concave) from the outside. Therefore, you would expect your



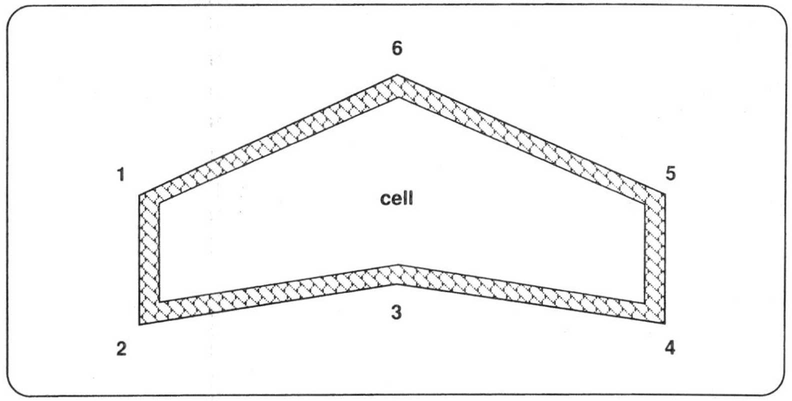


*Figure* 27. The prisoner's dilemma: Which corner to choose?

friend to begin digging there. Similarly, only number 3 is convex from the inside, so your friend will probably expect you to begin digging there as well.

Now what is your friend's motivation to dig at this particular corner? It is you! He sees you choosing this corner for the same reason that you see him choosing it. Notice that we can assign no causal sequence in this case and therefore no simple hierarchy of levels. Instead of causal linearity, we have causal circularity. No one decided on the plan. Instead, the plan was a mutual creation guided by a higher purpose—the prisoner's escape.

Douglas Hofstadter has called this kind of situation a tangled hierarchy—a hierarchy that is so mixed up that we cannot tell which is higher and which is lower on the hierarchical totem pole. Hofstadter thinks that self-reference may come out of such a tangled hierarchy.[21] I suspect that the situation in the brain-mind, with consciousness collapsing the wave function but only when awareness is present, is a tangled hierarchy and that our immanent self-reference is of tangled hierarchical origin. An observation by a self-referential system is where the von Neumann chain stops.

## IRREVERSIBILITY AND TIME'S ARROW

When is a measurement complete? The idealist says that it is complete only when a self-referential observation has taken place. In contrast, some physicists argue that the measurement terminates whenever a detector detects a quantum event. What is a detector as opposed to any old measurement apparatus? A detector's detection is *irreversible*, they say.

What is irreversibility? There are in nature certain processes that may be called reversible because you cannot tell the direction of time by looking at these processes in reverse. An example is the motion of a pendulum (at least for a short while); if you take a picture of its motion and then run it backward, there is no discernible difference. In contrast, an irreversible process is one that cannot be filmed in reverse without giving away its secret. For example, suppose while filming the motion of the pendulum on the table, you were also filming a cup that fell and broke during the filming. When you run the film in reverse, the fragments of the cup jumping off the floor and becoming whole again will give away your secret—that you are running the film in time-reverse.

To see the difference between a reversible measurement apparatus and a detector, consider an example. Photons have a two-valued characteristic called polarization: an axis that lies along (or is polarized along) only one of two perpendicular directions. Polaroid sunglasses polarize ordinary unpolarized light. They transmit only those photons that have a polarization axis parallel to that of the glasses. To test this, hold two polaroid glasses perpendicular to each other and look through them. You will see only darkness. Why? Because one polaroid lens polarizes the photons vertically (say), but the other lens transmits only photons polarized horizontally. In other words, the two lenses together act as a double filter that screens out all light.

A photon polarized at an angle of 45 degrees to the horizontal is a coherent superposition of half vertically polarized and half horizontally polarized states. If the photon passes through a polarizer-box with both horizontal and vertical polarization channels, it emerges at random either in the vertically polarized or in the horizontally polarized channel. This can be seen from pointer readings on detectors placed behind each channel (fig. 28a).

Now suppose that in the arrangement of figure 28a, we place a 45-degree polarizer in front of the photons before they are detected (fig. 28b). The photon is found to be reconstructed back to its original state of 45-degree polarization, a coherent superposition; it is regenerated. Thus the polarizer alone is not enough to measure the photons—since the photons still retain their potential to become



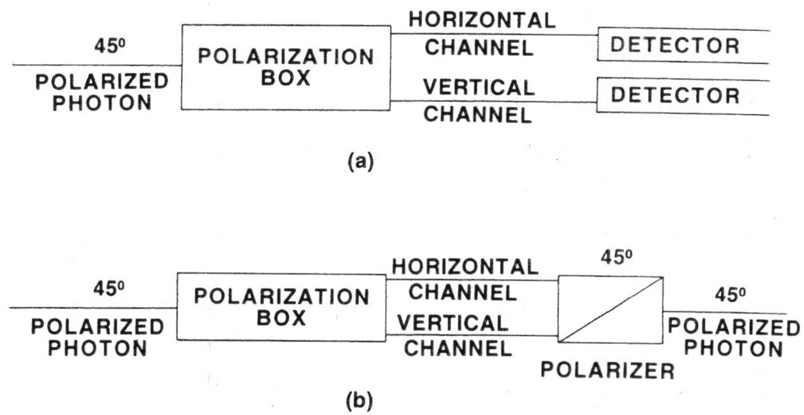


*Figure 28.* Experiments with 45-degree polarized photons.

a coherent superposition. A detector where irreversible processes take place, such as a fluorescent screen or a photographic film, is needed for measurement.

If you think in terms of time-reversal, the motion of the photons polarized at 45 degrees passing through the polarizer box and then again through the 45-degree polarizer is time reversible. If, however, the photons are detected by some detector with irreversible processes, when you imagine the process backward, you are able to discern between forward and backward.

Recall the story about a scene filmed for a silent movie. The heroine was supposed to be tied to a railroad track while a train sped toward her. In the movie's story line she would be saved—the train would stop just in the nick of time. Since the actress (understandably) was reluctant to risk her life, the director shot the whole scene backward—starting with the actress tied to the tracks while the train was next to her in full stop. Then the train was run backward. But what do you think people saw when the film was run in reverse? In those days trains were fueled by coal-burning boiler. In the backward-running film, the smoke flew into the stack instead of flowing out and thus gave away the secret of the film. The time evolution of smoke is irreversible.

Does this mean that a solution to the problem of quantum measurement is at hand—and without assuming the involvement of consciousness? We have only to recognize the irreversibility of certain measurement apparatuses called detectors, and then perhaps we can jump out of the von Neumann chain. Once these detectors have done their job, the quantum coherent superposition can no longer be regenerated and can truly be said, therefore, to have terminated.[22] But is that really so?

The question is, Is the detector enough to terminate the von Neumann chain? Von Neumann's answer is no. The detector must become a coherent superposition of pointer readings for the simple reason that ultimately, it, too, obeys quantum mechanics. The same is true for any subsequent measurement apparatus—reversible or "irreversible," the von Neumann chain continues.

The point is that the quantum Schrödinger equation is time reversible: It does not change if time is changed to minus time. Any macrobody obeying a time-reversible equation cannot be truly irreversible in its behavior, as shown by the mathematician Jules-Henri Poincaré.[23] Thus the conventional wisdom arises that absolute irreversibility is impossible; the apparent irreversibility that we see in nature has to do with the small probability that exists for a complex macrobody to retrace its path of evolution back to an initial configuration that has more relative order.

Considering irreversibility yields an important lesson. Although ultimately, all objects are quantum objects, the apparent irreversibility of some macro objects enables us to distinguish approximately between classical and quantum. We can say that a quantum object is one that regenerates, while a classical object has a long, long regeneration time. In other words, while quantum objects have no discernible retainment of their history—no memory—classical objects such as detectors can be said to have a memory in the sense of requiring a long time to erase the memory.

Another important issue arises: If there is no ultimate irreversibility in the motion of matter, how does the idealist interpretation handle the notion of unidirectional flow of time, time's arrow? In the idealist interpretation, time is a two-way street in the transcendent domain, showing signs of only approximate irreversibility for motion of more and more complex objects. When consciousness collapses the wave function of the brain-mind, it manifests the subjective one-way time that we observe. Irreversibility and time's arrow enter nature in the process of collapse itself, in quantum measurement, as the physicist Leo Szilard suspected long ago.[24]

It would seem that irreversibility of detectors does not solve the problem of measurement. Such a solution cannot be invoked unless we are ready to accept irreversibility, in the form of randomness, as



being even more fundamental than quantum mechanics. There is a proposal to do just that.[25]

Suppose that matter is fundamentally random and that the random behavior of a substratum of particles, through occasional fluctuations, generates the approximate orderly behavior that we may call quantum. If such were the case, quantum mechanics itself would be an epiphenomenon—as would all other orderly behavior. No experimental data support such a theory, although it would be an ingenious solution to the measurement problem if it could be proven. Some physicists do assume, however, that an underlying medium exists that causes the randomness; they draw an analogy with the underlying random motion of molecules that causes the random motion (called Brownian motion) of pollen grains in water when seen under a microscope. The assumption of an underlying medium, however, runs contrary to Aspect's experiment, unless it accommodates nonlocality. It is hard to accept nonlocal Brownian motion within material realism.

## The Nine Lives

Stephen Hawking says: "Every time I hear about Schrödinger's cat, I want to reach for my gun." Almost every physicist has had a similar impulse. Everyone wants to kill the cat—the paradox of the cat, that is—but it seems to have nine lives.

In the first life, the cat is treated statistically, as part of an ensemble. The cat is offended (because its singularity is denied in this ensemble interpretation) but not wounded.

In the second life, the cat is viewed as an example of the quantum/classical dichotomy by the divisive philosophers of macrorealism. The cat refuses to trade its life/death dichotomy for another dichotomy.

In the third life, the cat is confronted with irreversibility and randomness, but the cat says, Prove it.

In the fourth life, the cat confronts the hidden variables (the idea that its state never becomes dichotomous but is really completely determined by hidden variables) and what happens is still hidden.

In the fifth life, the neo-Copenhagenists try to do away with the cat using the philosophy of logical positivism. By most judgments, the cat escapes unscathed.

In the sixth life, the cat encounters many worlds. Who knows, it may have perished in some universe, but as far as we can tell, not in this one.

In the seventh life, the cat meets Bohr and his complementarity, but the question What constitutes a measurement? saves it.

In the eighth life, the cat meets consciousness (of a dualistic vintage) face-to-face, but Wigner's friend saves it.

Finally, in the ninth life, the cat finds salvation in the idealist interpretation. Here ends the story of the nine lives of Schrödinger's cat.[26]

# *Chapter 7*

# I CHOOSE, THEREFORE I AM

WE HAVE NOT YET CONFRONTED the important question What is consciousness? And how does one distinguish between consciousness and awareness?

Alas, a definition of consciousness is not easy. The word *consciousness* derives from two words: the Latin verb *scire*, which means to know, and the Latin preposition *cum*, which means with. Thus consciousness, etymologically, means "to know with."

In the *Oxford English Dictionary*, moreover, there are not one but six definitions of the word *consciousness*:

1. Joint or mutual knowledge.
2. Internal knowledge or conviction, especially of one's own ignorance, guilt, deficiencies, and so forth.
3. The fact or state of being conscious or aware of anything.
4. The state or faculty of being conscious as a condition or concomitant of all thought, feeling, and volition.
5. The totality of the impressions, thoughts, and feelings which make up a person's conscious being.
6. The state of being conscious regarded as the normal condition of healthy waking life.

None of these definitions is completely satisfactory, but considered all together they provide an approximate understanding of what consciousness is. Imagine a situation in which each of these