Chapter 23

Schrödinger's Cat

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Schrödinger's Cat

Erwin Schrödinger's goal for his infamous cat-killing box was to discredit certain non-intuitive implications of quantum mechanics, of which his wave mechanics was the second formulation. Schrödinger's wave mechanics is continuous mathematically, and deterministic. Werner Heisenberg's matrix mechanics is discontinuous and indeterministic.

Schrödinger did not like Niels Bohr's idea of "quantum jumps" between Bohr's "stationary states" - the different "energy levels" in an atom. Bohr's "quantum postulate" said that the jumps between discrete states emitted (or absorbed) energy in the amount $h\nu = E_2 - E_1$.

Bohr himself did not accept Albert Einstein's 1905 hypothesis that the emitted radiation is a *discrete* quantum of energy $h\nu$, later known as a *photon*. Until well into the 1920's, Bohr and Max Planck, the original inventor of the quantum hypothesis believed radiation was a continuous wave of the kind defended by Schrödinger. This raised the question of wave-particle duality, which Einstein saw as early as 1909.

It was Einstein who originated the suggestion that the *superposition* of Schrödinger's wave functions implied that two different physical states could exist at the same time. This was a serious interpretational error that plagues the foundation of quantum physics to this day.

This error is found frequently in discussions of so-called "entangled" states (see chapter 20).

Entanglement occurs only for atomic level phenomena and over limited distances that preserve the coherence of two-particle wave functions by isolating the systems (and their eigenfunctions) from interactions with the environment.

We never actually "see" or measure any system (whether a microscopic electron or a macroscopic cat) in two distinct states. Quantum mechanics simply predicts a significant probability of the system being found in these different states. And these probability predictions are borne out by the statistics of large numbers of identical experiments.

The Pauli Exclusion Principle says (correctly) that two identical indistinguishable (fermion) particles cannot be in the *same place at the same time*. Entanglement is often interpreted (incorrectly) as saying that a single particle can be in *two places at the same time*. Dirac's *principle of superposition* does not say that a particle is in two states at the same time, only that there is a non-zero probability of finding it in either state should it be measured.

Einstein wrote to Schrödinger with the idea that the random decay of a radioactive nucleus could be arranged to set off a large explosion. Since the moment of decay is unknown, Einstein argued that the superposition of decayed and undecayed nuclear states implies the superposition of an explosion and no explosion. It does not. In both the microscopic and macroscopic cases, quantum mechanics simply estimates the probability amplitudes for the two cases.

Many years later, RICHARD FEYNMAN made Einstein's suggestion into a nuclear explosion! (What is it about some scientists?)

Einstein and Schrödinger did not like the fundamental randomness implied by quantum mechanics. They wanted to restore determinism to physics. Indeed Schrödinger's wave equation predicts a perfectly deterministic time evolution of the wave function. But what is evolving deterministically is only abstract *probabilities - pure information*. And these probabilities are confirmed only in the *statistics* of large numbers of identically prepared experiments. Randomness enters only when a measurement is made and the wave function "collapses" into one of the possible states of the system.[1]

Schrödinger devised a variation on Einstein's idea in which the random radioactive decay would kill a cat. Observers could not know what happened until the box is opened.

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[1] See chapter 20.

The details of the tasteless experiment include:

- a Geiger counter which produces a macroscopic avalanche of electrons when an alpha particle passes through it,
- a bit of radioactive material with a decay half-life likely to emit an alpha particle in the direction of the Geiger counter during a time T,
- an electrical circuit, energized by the Geiger counter electrons, which drops a hammer,
- a flask of a deadly hydrocyanic acid gas, smashed open by the hammer.

The gas will kill the cat, but the exact time of death is unpredictable and random because of the irreducible quantum indeterminacy in the time of decay (and the direction of the decay particle, which might miss the Geiger counter!).

This thought experiment is widely misunderstood. It was meant (by both Einstein and Schrödinger) to suggest that quantum mechanics describes the simultaneous (and obviously contradictory) existence of a live and dead cat.

Here is the famous paradox with a cat both dead and alive.

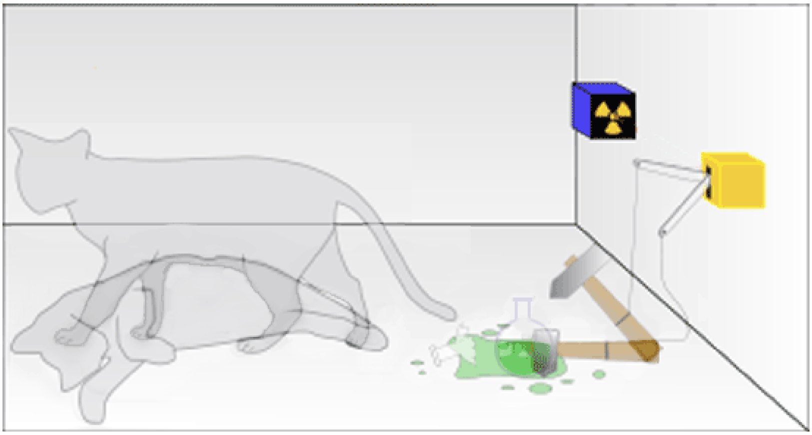

Figure 23-26. What the statistics from multiple experiments give us is the probability of finding a live or dead cat, in this case half the cats are found dead and half alive, but we never see a macroscopic superposition of both.

But quantum mechanics claims only that the time evolution of the Schrödinger wave functions will accurately predict the proportion of nuclear decays that will occur in a given time interval.

Quantum "probability amplitudes" do allow interference between the possible states of a quantum object, but not between macroscopic objects like live and dead cats More specifically, quantum mechanics provides us with the accurate prediction that if this experiment is repeated many times, half of the experiments will result in dead cats.

Note that this is a problem in epistemology. What knowledge is it that quantum physics provides?

If we open the box at the time T when there is a 50% probability of an alpha particle emission. The most a physicist can know is that there is a 50% chance that the radioactive decay will have occurred and the cat will be observed as dead or dying. Here is the famous diagram with a cat both dead and alive.

If the box were opened earlier, say at T/2, there is only a 25% chance that the cat has died. Schrödinger's superposition of live and dead cats would look like this.

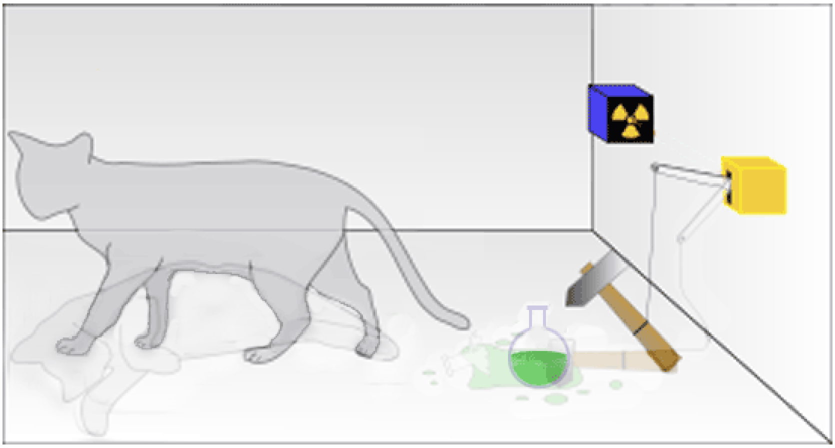

Figure 23-27. Here is the imaginary superposition of a mostly living cat and the pale shadow of a dead one.

If the box were opened later, say at 2T, there is only a 25% chance that the cat is still alive. Quantum mechanics is giving us only statistical information - knowledge about probabilities.

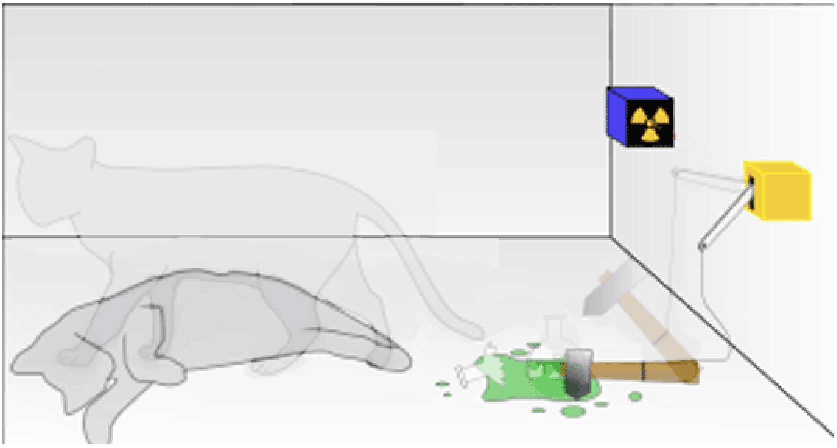

Figure 23-28. And here a mostlly dead cat, a vision of something that simply does not occur in macroscopic nature.

Schrödinger is simply wrong that the mixture of nuclear wave functions in the quantum world that accurately describes decay can be magnified to the macroscopic world to describe a similar mixture of live cat and dead cat wave functions and the simultaneous existence of live and dead cats.

The kind of coherent superposition of states needed to describe an atomic system as in a linear combination of states does not describe macroscopic systems (see Paul Dirac's explanation of the superposition of states using three polarizers in appendix C).

Instead of a linear combination of macroscopic quantum states, with quantum interference between the states, i.e.,

$$| Cat > = (1/\sqrt{2}) \,| Live > + (1/\sqrt{2}) \,| Dead >,$$

quantum mechanics tells us only that there is 50% chance of finding the cat in either the live or dead state, i.e.,

$$Cats = (1/2) \, Live + (1/2) \, Dead.$$

Just as in the quantum case, this probability prediction is confirmed by the statistics of repeated identical experiments, but no interference between these macroscopic states is ever seen.

What do exist simultaneously in the macroscopic world are genuine *alternative possibilities* for future events. There is the real possibility of a live or dead cat in any particular experiment. Which one is found is irreducibly random, unpredictable, and a matter of pure chance.

Genuine alternative possibilities is what bothered physicists like Einstein, Schrödinger, and Max Planck who wanted a return to deterministic physics. It also bothers determinist and compatibilist philosophers who have what William James calls an "antipathy to chance." Ironically, it was Einstein himself, in 1916, who discovered the existence of irreducible chance, in the elementary interactions of matter and radiation.

Until the information comes into existence, the future is indeterministic. Once information is macroscopically encoded, the past is determined.

How Information Physics Resolves the Cat Paradox?

As soon as the alpha particle sets off the avalanche of electrons in the Geiger counter (an irreversible event with an entropy increase), new information is created in the world.

For example, a simple pen-chart recorder attached to the Geiger counter could record the time of decay, which a human observer could read at any later time. Notice that, as usual in information creation, energy expended by a recorder increases the entropy more than the increased information decreases it, thus satisfying the second law of thermodynamics.

Even without a mechanical recorder, the cat's death sets in motion biological processes that constitute an equivalent, if gruesome, recording. When a dead cat is the result, a sophisticated autopsy can provide an approximate time of death, because the cat's body is acting as an event recorder. There never is a superposition (in the sense of the simultaneous existence) of live and dead cats.

The cat paradox points clearly to the information physics solution to the problem of measurement. Human observers are not required to make measurements. In this case, information is in the cat's body.

The cat is the observer.

In most physics measurements, any new information is captured by an apparatus well before any physicist has a chance to read any dials or pointers that indicate what happened. Indeed, in today's high-energy particle interaction experiments, the data may be captured but not fully analyzed until many days or even months of computer processing establishes what was observed. In this case, the experimental apparatus is the observer.

And, in general, the universe is its own observer, able to record (and sometimes preserve) the information created.

The basic assumption made in Schrödinger's cat thought experiments is that the deterministic Schrödinger equation describing a microscopic superposition of decayed and non-decayed radioactive nuclei evolves deterministically into a macroscopic superposition of live and dead cats.

But since the essence of a "measurement" is an interaction with another system (quantum or classical) that creates information to be seen (later) by an observer, the interaction between the nucleus and the cat is more than enough to collapse the wave function. Calculating the probabilities for that collapse allows us to estimate the probabilities of live and dead cats. These are probabilities, not probability amplitudes. They do not interfere with one another.

After the interaction, they are not in a superposition of states. We always have either a live cat or a dead cat, just as we always observe a complete photon after a polarization measurement and not a superposition of photon states, as P.A.M. Dirac explains so simply and clearly[2] .

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[2] see appendix C