Schrödinger's cat

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Schrödinger's Cat: When the nucleus (bottom left) decays, the Geiger counter (bottom centre) may sense it and trigger the release of the gas. In one hour, there is a 50% chance that the nucleus will decay, the gas will be released and the cat killed.

Schrödinger's cat is a seemingly paradoxical thought experiment devised by Erwin Schrödinger that attempts to illustrate the incompleteness of the Copenhagen interpretation when going from subatomic to macroscopic systems. Schrödinger proposed his "cat", after a suggestion of Albert Einstein's, stating that if a scenario existed where a cat could be so isolated from external interference (decoherence), the state of the cat can only be known as a superposition (combination) of possible rest states (eigenstates), because finding out (*measuring the state*) cannot be done without the observer interfering with the experiment — the measurement system (the observer) is entangled with the experiment.

The thought experiment serves to illustrate the strangeness of quantum mechanics and the mathematics necessary to describe quantum states. The idea of a particle existing in a superposition of possible states, while a fact of quantum mechanics, is a concept that does not easily scale to large systems (like cats), which are not indeterminably probabilistic in nature. Philosophically, these positions which emphasize either probability or determined outcomes are called (respectively) positivism and determinism.

Contents

The thought experiment

Schrödinger wrote:

> One can even set up quite ridiculous cases. A cat is penned up in a steel chamber, along with the following device (which must be secured against direct interference by the cat): in a Geiger counter there is a tiny bit of radioactive substance, so small, that perhaps in the course of the hour one of the atoms decays, but also, with equal probability, perhaps none; if it happens, the counter tube discharges and through a relay releases a hammer which shatters a small flask of hydrocyanic acid. If one has left this entire system to itself for an hour, one would say that the cat still lives if meanwhile no atom has decayed. The psi-function of the entire system would express this by having in it the living and dead cat (pardon the expression) mixed or smeared out in equal parts.
>
> It is typical of these cases that an indeterminacy originally restricted to the atomic domain becomes transformed into macroscopic indeterminacy, which can then be resolved by direct observation. That prevents us from so naively accepting as valid a "blurred model" for representing reality. In itself it would not embody anything unclear or contradictory. There is a difference between a shaky or out-of-focus photograph and a snapshot of clouds and fog banks.[1]

The above text is a translation of two paragraphs from a much larger original article, which appeared in the German magazine *Naturwissenschaften* ("Natural Sciences") in 1935.[2]

It was intended as a discussion of the EPR article published by Einstein, Podolsky and Rosen in the same year. Apart from introducing the cat, Schrödinger also coined the term "entanglement" (German: Verschränkung) in his article.

The experiment must be shielded from the environment to prevent quantum decoherence from inducing wavefunction collapse.

Schrödinger's famous *Gedankenexperiment* poses the question: *when* does a quantum system stop existing as a mixture of states and become one or the other? (More technically, when does the actual quantum state stop being a linear combination of states, each of which resemble different classical states, and instead begin to have a unique classical description?) If the cat survives, it remembers only being alive. But explanations of the EPR experiments that are consistent with standard microscopic quantum mechanics require that macroscopic objects, such as cats and notebooks, do not always have unique classical descriptions. The purpose of the thought experiment is to illustrate this apparent paradox: our intuition says that no observer can be in a mixture of states, yet it seems cats can be such a mixture. Are cats required to be observers, or does their existence in a single well-defined classical state require another external observer? Each alternative seemed absurd to Albert Einstein, who was impressed by the ability of the thought experiment to highlight these issues; in a letter to Schrödinger dated 1950 he wrote:

An illustration of *both* states, a dead and living cat. According to quantum theory, after an hour the cat is in a quantum superposition of coexisting alive and dead states. Yet when we look in the box we expect to see only one of the states, not a mixture of them.

> You are the only contemporary physicist, besides Laue, who sees that one cannot get around the assumption of reality—if only one is honest. Most of them simply do not see what sort of risky game they are playing with reality—reality as something independent of what is experimentally established. Their interpretation is, however, refuted most elegantly by your system of radioactive atom + amplifier + charge of gun powder + cat in a box, in which the psi-function of the system contains both the cat alive and blown to bits. Nobody really doubts that the presence or absence of the cat is something independent of the act of observation.

But perhaps it was inevitable that Einstein would be impressed with Schrödinger's cat—Einstein had previously suggested to Schrödinger a similar paradox involving an unstable keg of gunpowder, instead of a cat. Schrödinger had taken the next step of applying quantum mechanics to an entity that may or may not be conscious, to further illustrate the putative incompleteness of quantum mechanics.

Copenhagen interpretation

In the Copenhagen interpretation of quantum mechanics, a system stops being a superposition of states and becomes either one or the other when an observation takes place. This experiment makes apparent the fact that the nature of measurement, or observation, is not well defined in this interpretation. Some interpret the experiment to mean that while the box is closed, the system simultaneously exists in a superposition of the states "decayed nucleus/dead cat" and "undecayed nucleus/living cat", and that only when the box is opened and an observation performed does the wave function collapse into one of the two states. More intuitively, some feel that the "observation" is taken when a particle from the nucleus hits the detector. This line of thinking can be developed into Objective collapse theories. In contrast, the many worlds approach denies that collapse ever occurs.

Quantum physics

$$\Delta x\, \Delta p \geq \frac{\hbar}{2}$$

Quantum mechanics

Introduction to...
Mathematical formulation of...

Fundamental concepts

Decoherence · Interference
Uncertainty · Exclusion
Transformation theory
Ehrenfest theorem · Measurement
Superposition · Entanglement

Experiments

Double-slit experiment
Davisson-Germer experiment

Steven Weinberg said:

> All this familiar story is true, but it leaves out an irony. Bohr's version of quantum mechanics was deeply flawed, but not for the reason Einstein thought. The Copenhagen

> interpretation describes what happens when an observer makes a measurement, but the observer and the act of measurement are themselves treated classically. This is surely wrong: Physicists and their apparatus must be governed by the same quantum mechanical rules that govern everything else in the universe. But these rules are expressed in terms of a wavefunction (or, more precisely, a state vector) that evolves in a perfectly deterministic way. So where do the probabilistic rules of the Copenhagen interpretation come from?
>
> Considerable progress has been made in recent years toward the resolution of the problem, which I cannot go into here. It is enough to say that neither Bohr nor Einstein had focused on the real problem with quantum mechanics. The Copenhagen rules clearly work, so they have to be accepted. But this leaves the task of explaining them by applying the deterministic equation for the evolution of the wavefunction, the Schrödinger equation, to observers and their apparatus.[3]

Physicist Stephen Hawking once said, "When I hear of Schrödinger's cat, I reach for my gun," paraphrasing German playwright and Nazi Poet Laureate Hanns Johst's famous phrase "*Wenn ich 'Kultur' höre, entsichere ich meinen Browning!*" ("When I hear the word 'culture', I release the safety on my Browning," often paraphrased as something like, "When I hear the word 'culture,' I reach for my gun.")

Everett many-worlds interpretation & consistent histories

In the many-worlds interpretation of quantum mechanics, which does not single out observation as a special process, both states persist, but are decoherent from each other. In other words, when the box is opened, that part of the universe containing the observer and cat is split into two separate universes, one containing an observer looking at a box with a dead cat, one containing an observer looking at a box with a live cat.

Since the dead and alive states are decoherent, there is no effective communication or interaction between them. When an observer opens the box, they becomes entangled with the cat, so observer-states corresponding to the cat being alive and dead are formed, and each can have no interaction with the other. The same mechanism of quantum decoherence is also important for the interpretation in terms of Consistent Histories. Only the "dead cat" or "alive cat" can be a part of a consistent history in this interpretation.

Roger Penrose criticises this:

> "I wish to make it clear that, as it stands this is far from a resolution of the cat paradox. For there is nothing in the formalism of quantum mechanics that demands that a state of consciousness cannot involve the simultaneous perception of a live and a dead cat".[4]

although the mainstream view (without necessarily endorsing many-worlds) is that decoherence is the mechanism that forbids such simultaneous perception.[5][6]

Ensemble interpretation

The Ensemble Interpretation states that superpositions are nothing but subensembles of a larger statistical ensemble. That being the case, the state vector would not apply to individual cat experiments, but only to the statistics of many similar prepared cat experiments. Proponents of this interpretation state that this makes the Schrödinger's cat paradox a trivial non issue.

Objective collapse theories

According to objective collapse theories, superpositions are destroyed spontaneously (irrespective of external observation) when some objective physical threshold (of time, mass, temperature, irreversibility etc) is reached. Thus, the cat would be expected to have settled into a definite state long before the box is opened. This could loosely be phrased as "the cat observes itself", or "the environment observes the cat",

Practical applications

The experiment is a purely theoretical one, and the machine proposed is not known to have been constructed. Analogous effects, however, have some practical use in quantum computing and quantum cryptography. It is possible to send light that is in a superposition of states down a fiber optic cable. Placing a wiretap in the middle of the cable which intercepts and retransmits the transmission will collapse the wavefunction (in the Copenhagen interpretation, "perform an observation") and cause the light to fall into one state or another. By performing statistical tests on the light received at the other end of the cable, one can tell whether it remains in the superposition of states or has already been observed and retransmitted. In principle, this allows the development of communication systems that cannot be tapped without the tap being noticed at the other end. This experiment can be argued to illustrate that "observation" in the Copenhagen interpretation has nothing to do with consciousness (unless some version of Panpsychism is true), in that a perfectly unconscious wiretap will cause the statistics at the end of the wire to be different . Yet, one still cannot factor out the observation of the wiretap as having an effect upon the outcome.

In quantum computing, the phrase "cat state" often refers to the special entanglement of qubits where the qubits are in an equal superposition of all being 0 and all being 1, i.e. $|00\ldots0\rangle + |11\ldots1\rangle$.

Extensions

Although discussion of this thought experiment talks about *two* possible states, in reality there would be a *huge number* of possible states, since the temperature and degree and state of decomposition of the cat would depend on exactly when and how, as well as if, the mechanism was triggered, as well as the state of the cat prior to death.

A variant of the Schrödinger's Cat experiment known as the quantum suicide machine has been proposed by cosmologist Max Tegmark. It examines the Schrödinger's Cat experiment from the point of view of the cat, and argues that this may be able to distinguish between the Copenhagen interpretation and many worlds. Another variant on the experiment is Wigner's friend.

See also

- Basis function
- Double-slit experiment
- Interpretations of quantum mechanics
- Quantum suicide
- Quantum Zeno effect
- Schrödinger's cat in popular culture
- Schroedinbug
- Wigner's friend

References

1. ^ http://www.tu-harburg.de/rzt/rzt/it/QM/cat.html#sect5
2. ^ Schrödinger, Erwin (November 1935). "Die gegenwärtige Situation in der Quantenmechanik (The present situation in quantum mechanics)". *Naturwissenschaften*.
3. ^ Weinberg, Steven (November 2005). "Einstein's Mistakes". *Physics Today*: 31.
4. ^ Penrose, R. *The Road to Reality*, p807.
5. ^ Wojciech H. Zurek, Decoherence, einselection, and the quantum origins of the classical, *Reviews of Modern Physics* 2003, 75, 715 or [1]
6. ^ Wojciech H. Zurek, Decoherence and the transition from quantum to classical, *Physics Today*, 44, pp 36–44 (1991)

External links

- Erwin Schrödinger, The Present Situation in Quantum Mechanics (Translation)
- A Lazy Layman's Guide to Quantum Physics
- Quantum Mechanics and Schrodinger's Cat
- The many worlds of quantum mechanics
- The Straight Dope's Poem of Schroedinger's Cat
- The EPR paper

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