Physics 200-04

Schroedinger's Cat

Schroedinger began to have strong doubts about quantum mechanics in the 30's. He felt that the theory, especially with its strongly statistical foundation, was incomplete. In order to try to emphasise that it surely could not be a complete theory of nature, he devised a thought experiment. He said that we should imagine a cat, stuck into a box with absolutely soundproof, lightproof, etc walls. Inside the box was a small radioactive source which on average emitted one particle every 1 hour. Thus, after about 1 hour, there would be a 50-50 chance tht it had emitted one particle. There was in the box a detector which when it detected a particle would release a large iron ball which would fall and smash a bottle of HCN. Thus when the radioactive source had emitted a particle, the atmosphere that the cat breathed would fill with HCN and the cat would die.

To quote Schrödinger

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 an hour one of the atoms decays, but also, with equal probability, perhaps none (decay); 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 the cat still lives if meanwhile no atom has decayed. The psi-function (the wave describing the state) 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.

Now, the cat has a physical attribute, its life, which we could say has value 1 if the life attribute was "alive" and -1 if it was "dead". Ie, this life attribute is a two valued attribute.

After about 1 hours, the cat now has a 50-50 chance of being alive. What state are we to say that the cat is in?

[Of course we could ask exactly the same question if instead of the radioactive source in the box, we had a gambler who throws two die, once every 8 min., and smashes the bottle if the two die come up 12.i After 8 throws (approx 1hour) the cat again has a 50-50 chance of being alive.]

The question that Schroedinger askes is whether it makes any sense to

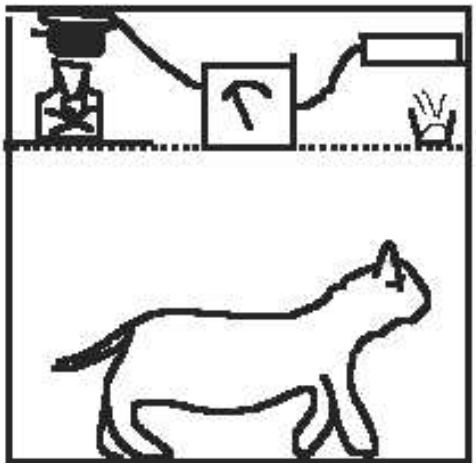
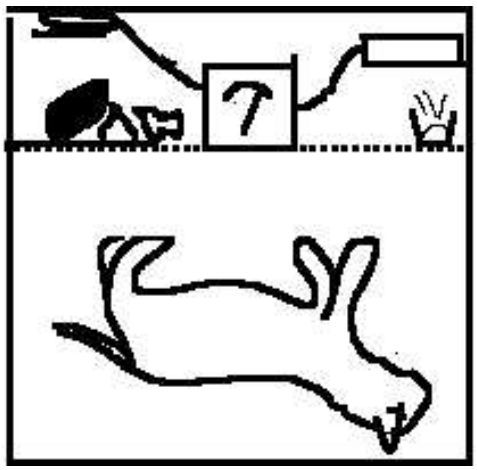


Figure 1: Aliveness = +1



Aliveness = -1

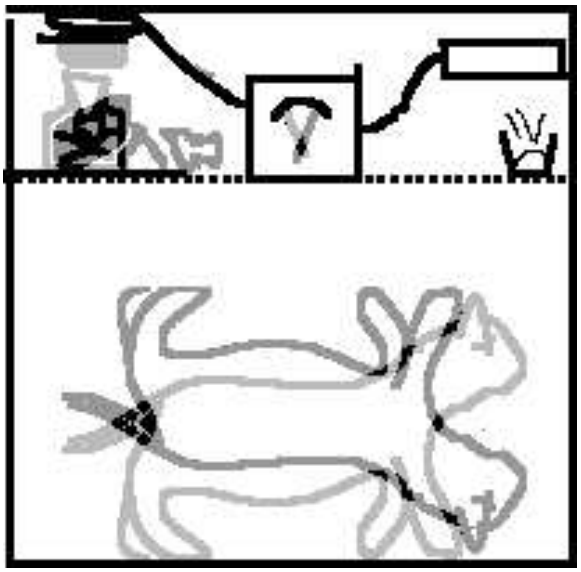


Figure 2: Superposition?

say that the cat, or rather the interior of the box, is in some state in which is a superposition of half alive and half dead cat.

Let us ask the question in a more definite way. Given that Aliveness attribute of the cat, is it possible to place the cat into a superposition of alive (+1) and dead(-1) state. Is it possible to carry out any experiment which could determine that the cat was in this superposition $|\Psi\rangle = \frac{1}{\sqrt{2}}(|alive\rangle + |dead\rangle)$ state. Now as we know from our analysis, as far as any measurement of the cat's being alive or dead (ie any determination of the aliveness attribute), this superposition will be no different from the case where the cat is classically alive-dead with a 50-50 ratio (ie, the dice thrower). However, in the case for example of the electron spin, where the initial attribute is say the spin in the z direction, we know that there is a different experiment, a different determination of some other physical attribute, the spin in the x direction, for which the dice-thrower experiment and the $|\Psi\rangle$ experiment would give different outcomes. Thus, in order to confront quantum theory, one has to not ask questions about whether the cat is alive or dead– both experiments will say that there is a 50-50 chance that it is alive– but whether it has the attribute which corresponds to the σ_1 operator.

We see immediatly from the analysis of the quantum cryptography and the no -cloning theorem, that if such an attribute exists, it must be exceedingly complicated. Because there are a whole host of physical processes which try to "copy" the aliveness of the cat. First of all, the state of the cat itself is a copy of the state of the atom. Then the molecues in the air in the box is a copy of the state of the atom, and the state of floor (vomit, etc) are also copies of the state of the atom, and of the aliveness of the cat. In each case, these copies destroy the ability to determine the superposition of the alive and dead cat, just as Eve's copying of Alice's bit which is the eigenstate of σ_1 destroy both Eve and Bob's ability to determine that it was ever in an eigenstate of σ_1 and left all the probabilities for both as $50 - 50$.

In the Alice Eve and Bob situation, the state of the joint system of Eve and Bob still reflected the initial state that Alice sent. The joint system is $\frac{1}{\sqrt{2}}(|1,1\rangle + |-1,-1\rangle)$. Ie, IF we measure some quantity shared by both Eve and Bob– for example the operator $\sigma_{B1}\sigma_{E1}$, it can distinguish between that state and the state $\frac{1}{\sqrt{2}}(|1,1\rangle - |-1,-1\rangle)$ which is the copy of the state $\frac{1}{\sqrt{2}}(|1\rangle + |-1\rangle)$ that Alice sent.

Ie, to make Schroedinger's cat a true test of quantum mechanics, one has

to ask if there is any way of doing an experiment which could determine which superposition the whole inside of the box were in. If one limits oneself to the aliveness attribute, then there is no difference between the dice throwing or the radioactive atom experiment.

One could of course ask in the quantum case, whether there is some ontological [≡ Study of being, rather than of knowledge] sense in which the two experiments differ. In the dice thrower case, while I might say that the cat is alive with 50-50 ratio, I would say that the cat does not share this uncertainty. The probability is one of my ignorance. The cat is "really" either alive or dead. In the quantum case however, one would have to say that ontologically, the issue is undetermined. One could imagine doing some impossibly difficult experiment, in which it would make a difference whether the cat **is** either alive or dead, and it is only my ignorance of its actual state which is at question, or if the cat were in the superposition of aliveness and deadness. The experiment would be impossibly difficult precisely because it would be so easy for some physical process to "copy" the aliveness state of the cat and destroying the possibility of doing the interference experiment with the cat alone, but would have to include everything that "copied" the aliveness attribute.

This thought experiment lies at the heart of the arguments about the meaning and interpretation of quantum mechanics. There is as yet no even widely agreed on resolution, just an agreement to ignore the question while using quantum mechanics to describe the physical world.