## Wigner's friend

Wigner's friend is a thought experiment in theoretical quantum physics, first conceived by the physicist Eugene Wigner in 1961, and developed into a thought experiment by David Deutsch in 1985.

The scenario involves an indirect observation of a quantum measurement: An observer W observes another observer F who performs a quantum measurement on a physical system.

The two observers then formulate a statement about the physical system's state after the measurement according to the laws of quantum theory.

However, in most of the interpretations of quantum theory, the resulting statements of the two observers contradict each other.

This reflects a seeming incompatibility of two laws in quantum theory: the deterministic and continuous time evolution of the state of a closed system and the probabilistic, discontinuous collapse of the state of a system upon measurement.

Wigner's friend is therefore directly linked to the measurement problem in quantum mechanics with its famous Schrödinger's cat paradox.

## The thought experiment

The thought experiment posits a friend of Wigner in a laboratory, and lets the friend perform a quantum measurement on a physical system (this could be a spin system or something analogous to Schrödinger's cat).

This system is assumed to be in a superposition of two distinct states, say, state 0 and state 1 (or "dead" and "alive", in the case of Schrödinger's cat).

When Wigner's friend measures the system in the 0/1-basis, according to quantum mechanics, they will get one of the two possible outcomes (0 or 1) and the system collapses into the corresponding state.

Now Wigner himself models the scenario from outside the laboratory, knowing that inside, his friend will at some point perform the 0/1-measurement on the physical system.

According to the linearity of the quantum mechanical equations, Wigner will assign a superposition state to the whole laboratory (i.e. the joint system of the physical system together with the friend):

The superposition state of the lab is then a linear combination of "system is in state 0/ friend has measured 0" and "system is in state 1/ friend has measured 1".

Let Wigner now ask his friend for the result of the measurement:

whichever answer the friend gives (0 or 1), Wigner would then assign the state "system is in state 0/ friend has measured 0" or "system is in state 1/ friend has measured 1" to the laboratory.

Therefore, it is only at the time when he learns about his friend's result that the superposition state of the laboratory collapses.

However, unless Wigner is considered in a "privileged position as ultimate observer", the friend's point of view must be regarded as equally valid, and this is where an apparent paradox comes into play:

From the point of view of the friend, the measurement result was determined long before Wigner had asked about it, and the state of the physical system has already collapsed.

When now exactly did the collapse occur?

Was it when the friend had finished their measurement, or when the information of its result entered Wigner's consciousness?

## Mathematical description

Assume for simplicity that the physical system is a two-state spin system S with states $|0\rangle_S$ and $|1\rangle_S$, corresponding to measurement results 0 and 1.

Initially, is in a superposition state

$$\alpha|0\rangle_S + \beta|1\rangle_S$$

and gets measured by Wigner's friend (F) in the $\{|0\rangle_S, |1\rangle_S\}$-basis. Then, with probability $|\alpha|^2$ F will measure 0 and with probability $|\beta|^2$, will measure 1.

From the friend's point of view, the spin has collapsed into one of its basis states upon his measurement, and hence, they will assign to the spin the state corresponding to their measurement result: If they got 0, they will assign the state $|0\rangle_S$ to the spin, if they got 1, they will assign the state $|1\rangle_S$ to the spin.

Wigner (W) now models the combined system of the spin together with his friend (the joint system is given by the tensor product $S \otimes F$).

He thereby takes a viewpoint outside of 's laboratory, which is considered isolated from the environment.

Hence, by the laws of quantum mechanics for isolated systems, the state of the whole laboratory evolves unitarily in time.

Therefore, the correct description of the state of the joint system as seen from outside is the superposition state

$$\alpha(|0\rangle_S \otimes |0\rangle_F) + \beta(|1\rangle_S \otimes |1\rangle_F),$$

where $|0\rangle_F$ denotes the state of the friend when they have measured 0, and $|1\rangle_F$ denotes the state of the friend when they have measured 1

For an initial state $|0\rangle_S$ of S, the state for $S \otimes F$ would be $|0\rangle_S \otimes |0\rangle_F$ after F 's measurement, and for an initial state $|1\rangle_S$, the state of $S \otimes F$ would be $|1\rangle_S \otimes |1\rangle_F$ . Now, by the linearity of Schrödinger's quantum mechanical equations of motion, an initial state $\alpha|0\rangle_S + \beta|1\rangle_S$ for S results in the superposition $\alpha(|0\rangle_S \otimes |0\rangle_F) + \beta(|1\rangle_S \otimes |1\rangle_F)$ for $S \otimes F$. .

**Discussion**

**Consciousness and Wigner's friend**

Eugene Wigner designed the thought experiment to illustrate his belief that consciousness is necessary to the quantum mechanical measurement process (and therefore, that consciousness in general must be an "ultimate reality" according to Descartes's "Cogito ergo sum" philosophy):

"All that quantum mechanics purports to provide are probability connections between subsequent impressions (also called 'apperceptions') of the consciousness".

Here, "impressions of the consciousness" are understood as specific knowledge about a (measured) system, i.e., the result of an observation.

This way, the content of one's consciousness is precisely all knowledge of one's external world and measurements are defined as the interactions which create the impressions in our consciousness.

Since the knowledge about any quantum mechanical wave function is based on such impressions, the wave function of a physical system is modified once the information about the system enters our consciousness.

This idea has become known as the "consciousness causes collapse" interpretation.

In the Wigner's friend thought experiment, this (Wigner's) view comes in as follows:
The friend's consciousness gets "impressed" by their measurement of the spin, and therefore they may assign a wave function to it according to the nature of their impression.

Wigner, having no access to that information, can only assign the wave function to the joint system of spin and friend after the interaction.

When he then asks his friend about the measurement outcome, Wigner's consciousness gets "impressed" by the friend's answer:

As a result, Wigner will be able to assign a wave function to the spin system, i.e., he will assign to it the wave function corresponding to the friend's answer.

So far, there is no inconsistency in the theory of measurement.

However, Wigner then learns (by asking his friend again) that the feelings/thoughts of his friend about the measurement outcome had been in the friend's mind long before Wigner had asked about them in the first place.

Therefore, the correct wave function for the joint system of spin and friend just after the interaction must have been either or , and not their linear combination.

Hence, there is a contradiction, specifically in the "consciousness causes collapse" interpretation.

Wigner then follows that "the being with a consciousness must have a different role in quantum mechanics than the inanimate measuring device”:

If the friend were replaced by some measuring device without a consciousness, the superposition state would describe the joint system of spin and device correctly.

In addition, Wigner considers a superposition state for a human being to be absurd, as the friend could not have been in a state of "suspended animation” before they answered the question.

This view would need the quantum mechanical equations to be non-linear.

It is Wigner's belief that the laws of physics must be modified when allowing conscious beings to be included.

**A counterargument**

A counterargument is that the superimposition of two conscious states is not paradoxical

– just as there  is no interaction between the multiple quantum states of a particle,

so the superimposed consciousnesses need not be aware of each other.

The state of the observer's perception is considered to be entangled with the state of the cat. The perception state "I perceive a live cat" accompanies the "live-cat" state and the perception state "I perceive a dead cat" accompanies the "dead-cat" state. ... It is then assumed that a perceiving being always finds his/her perception state to be in one of these two; accordingly, the cat is, in the perceived world, either alive or dead. ... I wish to make 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.

— Roger Penrose