Opinion and Perspectives

The Quantum Measurement Problem: How to Rescue a Cat from Schizophrenia?

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ABSTRACT

The implementation of quantum theory was presented to our macroscopic world by the "cat" thought experiment (*Gedanken experiment*) suggested by Erwin Schrödinger in 1935. In the same way, Pavlov's dog with its learning by conditioned reflexes was a similar symbol of Newtonian physics representing the deterministic view, and the cat as an animal became the symbol of quantum mechanics. Thought experiments are a common technique in physics. Before everything, it is important to see whether the experiment can be carried out at all, and it is unimportant how complex the relevant techniques to be used in the experiment. This is because there is only a design and a thought experiment. Imagination and materials are unlimited, and the only constraining factors are the laws of mathematics and physics. If you feel sorry for the cat, you might prefer the experiment suggested by Einstein, which uses a box containing a bomb, a photon, an electron, or playing cards. In this article, we reviewed possible solutions of the quantum measurement problem or quantum wavefunction collapse.

Key Words: Schrödinger's cat, measurement problem, wavefunction collapse

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Introduction

The definitions of quantum concepts can be applied not only at the level of molecules, atoms and sub-atomic particles when the energy differences between alternative possibilities are very small, but also on larger scales (Penrose, 2005). The border between the microscopic quantum world and the macroscopic=macrouniversal classical world started to become evident in the 1980s. In 1983 it was shown that macroscopic systems could behave like quantum systems if they were sufficiently protected from the environment (Cadderia, 1983).

According to classical Newtonian physics, if the starting state of a mechanism is known, all later states can be predicted with great accuracy. This is deterministic thinking, according to which all results can be known with certainty from their causes. This determination is predictable. The influence of Newtonian physics can be seen in the field of neuropsychology, and is demonstrated in the conditioned reflex experiment with Pavlov's dog. In this experiment, a dog becomes accustomed to being fed after the sound of a bell. It is conditioned to being fed after the bell is sounded. When this is repeated sufficiently often (first the bell and then feeding), even if the dog is not fed after the sound of the bell its salivation increases. This experiment represents the irresistible attractiveness of causality by conditioned reflex in psychology. Everything can be predicted in advance!

As for quantum mechanics, it is proposed that all systems can basically be pictured in statistical terms. That is, the observable causality of the universe is connected to the probability of the total from very small systems to larger systems being 1. Thus, our causal understanding of the universe changes place towards the universe of probability with Schrödinger's wave function equation, and

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human beings take a central position. In this way, we are confronted with the role played by the observer. The laws of physics concerning the universe are referred to objective knowledge, and knowledge can only be acquired through and observer. But an observer can only verify the period of the observation, so that in some way the observer and the measurement come to mean one and the same thing.

The explanation of measurement must be an ontological-epistemological explanation where the one completes the other. The *ontic explanation* expresses its place in the physical universe and the empirical content – that which relies on experiments. The epistemic explanation on the other hand researches into the make-up of this information obtained by measurement, and the meaning of the theory of this information, by examining which objects are characterized by physical reality. The characterization of epistemic state and the characterization of mathematical state are not exactly the same. In the history of philosophy, philosophers have emphasized at least three different concepts of determinacy, and these must be examined in order to understand in what sense QM is deterministic. Epistemic determinism states that information about the state of a physical object can be derived from information about the previous state of the object at a particular time. Causal determinism maintains that the state of a physical object at a particular time can show its state at a later time by forming universal laws of process. Ontic determinism means accepting that physical objects will exist in the future on the basis that they exist in the present.

Commentators on QM use the expression 'determinism' with a different meaning. Niels Bohr, used causality and determinism with the same meaning, but emphasized epistemic determinism. Max Born, however, used the expression 'determinism' with the meaning of a physical event at different times showing connectedness with another in a way that it is possible to guess its future and past physical state. David Bohm also discusses determinism: *"...the output of a cause, the tendency in the production of an effect..."* In connection with all of these, there are such expressions in QM as strict determinism and loose determinism.

The most important thing which distinguishes classical physics from QM is the place of the characterization of the state of indeterminism. The source of this state of indeterminism is best stated by Heisenberg:

> "... If we know the present for certain, we can calculate the future... What is wrong is not the result, but the premise. It is not possible in principle to know everything which defines the present."

Schrödinger's Poor Cat

In the experiment that Schrödinger designed, a cat is placed in a box that is perfectly sealed from the environment along with a radioactive atom with a half-life of 10 minutes. Schrödinger designed the experiment with the idea that by using the knowledge that the radioactive atom had entered a superposed state of its own accord he could also put the macroscopic cat into a superposed state.

If we leave a radioactive atom alone without an observer, it enters a state in which its decayed and non-decayed states are superposed. That is, if we take a nitrogen-13 atom with a half-life of 10 minutes and examine its state at the end of 10 minutes, it will either have decayed or not decayed. That is, the chance of each possibility is 50%. In a superposed state, the chances of a decayed state and a non-decayed state are equal. As for the cat experiment, a detector inside the box detects the radiation when the atom decays, and immediately a mechanism attached to it springs into action and releases poisonous gas from a flask, which kills the cat. If the cat is lucky, the atom does not decay, the detector remains untriggered and the cat lives. However, until the box is opened and examined, the living or non-living states of the cat enter a superposed state, just like the states of the decaying atom. At the end of ten minutes, is the cat dead, or alive, or both dead and alive?

We can perform Schrödinger's cat experiment with playing cards. If we set up a card on edge in ideal conditions, then according to classical physics if there is no intervention from the environment it will stay there forever. But when we think along the lines of Schrödinger's cat experiment or QM, we can see that the card will fall after a few seconds. However, if it is very well balanced, it could fall either way – left or right. That is, until it falls, these directions are in a superposed state.

Schrödinger's cat is a thought experiment, usually described as a paradox, devised by Austrian physicist Erwin Schrödinger in 1935. It illustrates what he saw as the problem of the Copenhagen interpretation of quantum mechanics applied to everyday objects. The thought experiment presents a cat that might be alive or dead, depending on an earlier random event. In the course of developing this experiment, he coined the term *Verschränkung* (entanglement). 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 that 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."

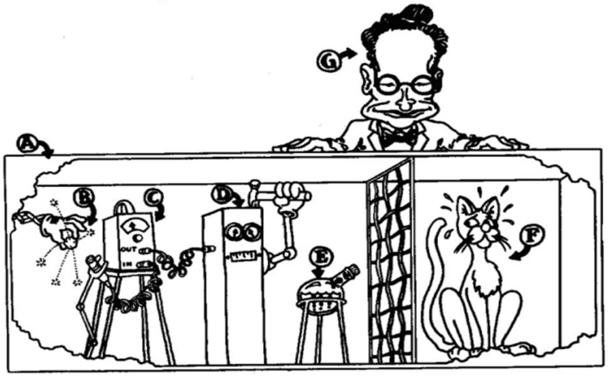

Figure. Experimental setup for Schrödinger's cat experiment. A: Experiment box, B: Radioactive material, C: Geiger counter, measuring emission from the radioactive material, D: Mechanism with a hammer, activated by a signal from the Geiger counter, E: Glass flask containing volatile poisonous substance, F: the poor cat, and G: the observer, experimenter, or physicist.

Ways to Save the Cat from its Psychosis

1. The Copenhagen Interpretation

How can it be understood that the cat is both alive and dead at the same time? Well, it can be achieved by a (conscious) experimenter outside opening the box to see the result! According to the pioneering Copenhagen interpretation of Niels Bohr and David Bohm, which is also called the orthodox interpretation, opening the box and seeing the cat is an act of 'observation'. The state of any physical system suffers a kind of 'collapse' upon observation. The act of measurement has collapsed the state formed of multiple states superposed on each other, that is two choices existing simultaneously (*superposition* = dead + alive), into a single state of the cat (either dead or alive). The cat experiences a collapse into either a living or a dead state under the influence of the observer. Consequently, the experimenter sees the cat as either living or dead in accordance with the normal perceptions of daily life. The observer can never see the cat in a superposed dead + alive state. But can the experimenter understand or perceive that the cat is in a superposed state? That is, can he get an idea of the cat's fate without opening the lid?

One of the main problems in QM is whether measurement is accepted as complete after the result has been learned by an observer, or after it has been recorded by the apparatus. As will be seen later, according to the Copenhagen interpretation of QM, knowing that the measurement has been made causes a change in the observer's information state which existed before the measurement was made. That is, it causes a reduction in information. The observer's information state is shown by information depending on experience obtained at the end of the measurement process. These information states are dependent on the observer's information state (subjective). Because of this relationship, a 'subjective observer factor' stands in between a condition which exists in physical reality and a condition which is alleged to be about to happen. It is not possible to escape this subjectivity.

The world is separated into two parts – quantum existence (probability waves) and real objects which can be measured in a classical way. With real objects, only those with a single measurement result can be accepted as real. Aside from this, nothing can be said about reality. But if we take an atom in order to perform an experiment on it and then some time later we perform the experiment, it is not possible to say that one thing or another is true about the atom in the time which has passed between preparing and performing the experiment. We can only talk about reality at the moment when the atom is observed or measured, when the system has 'collapsed'.

The Copenhagen interpretation distinguishes micro-universal quantum systems and macro-universal measurement instruments. The result is stabilized with the chain reaction which carries out the measurement by classical recording instruments of an event or body at the beginning (the passage of an electron through a gap, a photon or an atom), that is, the wave function collapses irreversibly. That which is seen by observation or measurement is the result of random choice. Things which are yet to be cannot be chosen. Possibilities and the uncertainties related to them are at the core of nature. Quantum amplitudes give the possibility of various results, and what is going to happen is stabilized at the moment of observation. The future cannot be ascertained from the specific, 'deterministic' rules of the past.

According to Heisenberg, the observer was included in the event in the Copenhagen interpretation. The function of the observer was more to record the events in space and time that is to decide and arrive at a definite judgment, so that it made no difference here whether the observer was an instrument or some kind of living being. This reminds the physicist that he has to examine a universe which he did not create himself and which can exist without him.

From the point of view of quantum physics the wave function of such a system can be written in this way:

$$|\psi_{\text{total}}\rangle = W|\text{dead cat}\rangle|\text{💣explosion}\rangle + z|\text{live cat}\rangle|\text{no explosion}\rangle$$

Or with playing cards in this way:

$$|\psi_{\text{total}}\rangle = W|\text{TOP}\rangle|\text{environment}\rangle + z|\text{BOTTOM}\rangle|\text{environment}\rangle$$

Whether or not there is an explosion (the fission of a radioactive substance, the poisonous gas coming out of the flask) are *environmental states*. Whether the card falls face up or face down may be decided by the photons which create the environmental conditions or by collisions with air molecules. According to John Bell's definition 'for all practical purposes', it can be written:

$$|\psi_{\text{total}}\rangle = w|\text{card face up}\rangle|?| + z|\text{card face down}\rangle|?|\rangle$$

Here, "?" symbolizes the unmeasured environmental effects. According to the Copenhagen interpretation of QM, because the equation is divided into two its representation collapses into one of them at random and the equation is reduced to a single result. For this reason, it is argued that the equation is indeterministic.

The Copenhagen school's measurement process can be represented symbolically in this way. **M;** *measurement*		
Any measurement in time t	Observer's information state SUBJECTIVE	Physical state which is expected to occur after time t SUBJECTIVE + OBJECTIVE
$\mathbf{M}_{\mathbf{mt}\rightarrow}$	$\rho_{t\rightarrow}$	$\mathbf{M}_{(\rho t)(t+T)}$

According to the Copenhagen school, a micro-universal state must be discussed using classical macro-universal terms. This is only possible, however, by using 'measuring device', 'particle measured' and the 'interaction' between them together. The Copenhagen school, despite accepting that the dynamic effects of the particle on the measuring device are not important, does not allow it to be regarded independently of the observer and the measuring device.

Starting out from the statement of measurement$_{mt}$, theoretical knowledge of a physical state which is expected to occur can be symbolized by Measurement$_{(\rho t)(t+T)}$. However, this theoretical knowledge is dependent on the state of knowledge of the observer, ρ_t. State of knowledge is a subjective concept. There is a subjective aspect of the prediction process arising from the observer's state of knowledge because the expected state is based on knowledge from an experiment carried out by measurements on the part of the observer. For this reason, when the Copenhagen interpretation of QM was made, only the statement 'The observer has made a definite subjective observation' can be valid. The dose of subjectivity in the Copenhagen interpretation has increased somewhat, because after the observer has made measurements, the system is characterized by ψMx rather than by ψM. This is a measurement process known as *state reduction*, and can also be called 'change in the state of knowledge of the observer'.

It is not possible to describe a quantum event without using the process of measuring device, measured particle and the interaction between them. According to the Copenhagen interpretation, it is impossible to separate what is measuring and what is measured because it is not possible to describe separately the functions of the measuring and measured objects. This brings about a blending of object (measured) and subject (measuring). This in a way is a blending into one another of the thing whose characteristics are discovered (measured – object) and the thing which is discovering these dynamic characteristics (measuring – subject). This is like a modern echo of Berkeley idealism.

Many physicists and philosophers have objected to the Copenhagen interpretation, both on the grounds that it is non-deterministic and that it includes an undefined measurement process that converts probability functions into non-probabilistic measurements. Einstein's comments "I, at any rate, am convinced that He (God) does not throw dice." and "Do you really think the moon isn't there if you aren't looking at it?" exemplify this. Bohr, in response, said "Einstein, don't tell God what to do".

Steven Weinberg in "Einstein's Mistakes", Physics Today, November 2005, page 31, 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 wave function (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 wave function, the Schrödinger equation, to observers and their apparatus."

The Copenhagen Interpretation gives special status to measurement processes without clearly defining them or explaining their peculiar effects. In his article entitled "Criticism and Counterproposals to the Copenhagen Interpretation of Quantum Theory," countering the view of Alexandrov that (in Heisenberg's paraphrase) "*the wave function in configuration space characterizes the objective state of the electron.*" Heisenberg says,

> "Of course the introduction of the observer must not be misunderstood to imply that some kind of subjective features are to be brought into the description of nature. The observer has, rather, only the function of registering decisions, i.e., processes in space and time, and it does not matter whether the observer is an apparatus or a human being; but the registration, i.e., the transition from the "possible" to the "actual," is absolutely necessary here and cannot be omitted from the interpretation of quantum theory.—Heisenberg, Physics and Philosophy, p. 137"

According to a poll at a Quantum Mechanics workshop in 1997, the Copenhagen interpretation is the most widely-accepted specific interpretation of quantum mechanics, followed by the many-worlds interpretation. Although current trends show substantial competition from alternative interpretations, throughout much of the twentieth century the Copenhagen interpretation had strong acceptance among physicists. Astrophysicist and science writer John Gribbin describes it as having fallen from primacy after the 1980s.

2. Psychophysical Parallelism

Even if we accept that the person who is the observer is at the end of the chain of devices (measurement instrument → measuring observer), it has to be asked where this chain of devices ends in the physiological parts of the human being (eye light-sensitive receptors in the retina → optic nerves visual cortex of the brain → conscious perception...). If it is decided that the measurement process ends in one of these physiological parts of the brain, the physiological changes at this end-point must be recognized as quantum mechanical. This is seen as a serious problem from the point of view of neurophysiology and quantum mechanics. It cannot be said that this point has yet been clarified.

Starting from here, John von Neumann (1903-1957) tried to solve the problem by bringing in psychophysical parallelism. Von Neumann was a mathematician and physicist, whose work *Mathematical Foundations of Quantum Mechanics* was published when he was only 23 years old. In von Neumann's opinion, if a cut-off is thought of between the real observer and the measurement instrument, it is possible to place this boundary anywhere in the observer's physiology. Von Neumann accepts the observer's consciousness as the true observer. However, it isn't as easy as that: if we can reduce and describe these physiological processes mechanically and totally, then there is no problem. But we do not have the complete answer to the physiological processes which everyone accepts as happening in the brain and the eye.

Von Neumann was against the Copenhagen interpretation's division into two of the world as observer and observed system/device. He proposed that these were one and the same thing and a new physical law had to come into operation for the wave function to collapse. This had to be something which existed in reality but which was not a physical object. He arrived at the belief that this must be 'consciousness'.

In a micro-universal system, when no measurement is made the system's universe exists of itself. But when any of its characteristics are measured, such as speed or position, an interaction with recognizable physical characteristics occurs between the system and the measurement device. Thus this means that the micro-universal object has two different pathways depending on whether it has or has not been measured. These can be symbolized according to von Neumann in this way: a process like $U \rightarrow U_t$ (where t represents the state of temporal advance) is a causal, deterministic process without an observer, while on the other side $U \rightarrow U^*$ is a process which is causal and depends on observation and measurement. Thinking in terms of thermodynamics, a causal process is accepted as a reversible process. A non-causal process is then an irreversible process. According to this, the causal process $U \rightarrow U_t$ is characterized as 'actually existing in nature', while the process $U \rightarrow U^*$ is characterized as 'existing by the observation of nature'. According to von Neumann, as long as these two states are not united, there will always be the problem of the observer in QM.

3. Many Worlds or Many Minds

The *many-worlds interpretation* (MWI), which Hugh Everett proposed in his doctoral thesis in 1957, was another proposal for solving the measurement problem in QM. Many-worlds is a postulate of quantum mechanics that asserts the objective reality of the universal wavefunction, but denies the reality of wavefunction collapse, which implies that all possible alternative histories and futures are real —each representing an actual "world" (or "universe"). It is also referred to as MWI, the relative state formulation, the Everett interpretation, the theory of the universal wavefunction, many-universes interpretation, or just many worlds. The original relative state formulation is due to Hugh Everett in 1957. Later, this formulation was popularized and renamed many-worlds by Bryce Seligman DeWitt in the 1960s and '70s.

The *many-minds interpretation* of quantum mechanics extends the many-worlds interpretation by proposing that the distinction between worlds should be made at the level of the mind of an individual observer. The concept was first introduced in 1970 by H. Dieter Zeh as a variant of the Hugh Everett interpretation in connection with quantum decoherence, and later (in 1981) explicitly called a many or multi-consciousness interpretation. The name many-minds interpretation was first used by David Albert and Barry Loewer in their 1988 work interpreting the Many Worlds Interpretation.

It has been called the many-minds interpretation by some. The expression 'many minds' expresses the conscious states divided in different brains. In place of using a wave function to characterize the state of measuring and measured objects, a wave function in which these objects exist and which characterizes the whole universe is used in the calculations. However, it is not clear whether Everett meant the whole of the micro-universe or the whole universe which includes both the micro and macro-universes. The universal wave function expresses the objective wave function of the universe. The relative wave function expresses the subjective information of the sub-sections of the universe. Therefore, while the universal is a deterministic, necessitarian theory, from a subjective point of view it is indeterminist because it does not show permanence. Subjective state functions can be derived from objective universal wave functions (Wheeler, 1957; Everett, 1955).

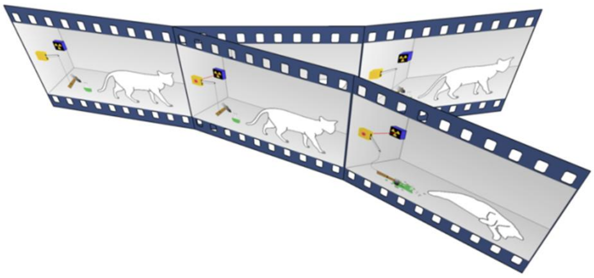

Figure. The quantum-mechanical "Schrödinger's cat" paradox according to the many-worlds interpretation. In this interpretation every event is a branch point; the cat is both alive and dead, irrespective of whether the box is opened, but the "alive" and "dead" cats are in different branches of the universe, both of which are equally real, but which cannot interact with each other.

Let's have a look first at what is meant by 'many worlds'. It is a partially or totally closed set composed of mixed, causally related sub-systems which are mutually interactive. The worlds are superposed elements which do not interact with each other, which Everett called a universal wave function. What Everett understood without measuring was that one sub-system is associated with another sub-system's attribute values. This is an irreversible interaction. When this interaction starts a rising process in an object or a system, a high-value change is brought about in that same object or system. A person with a conscious and aware brain is not needed.

Everett's many minds interpretation says that the quantum positions of the unobserved atom are not just possibilities, but are real. In this strange theory, each one of the possible states is true in different universes. According to Everett, everything possible is found in a giant universe as small possible universes. People observing each one of these states exist in many sub-universes, but these people do not know about each other. All events occur in this world. In this model, there are no transfers of reality created by observers from possibility to reality.

To put this in more technical terms, he proposes that when we think of the ψ-psi function as $\psi=\Sigma a_i\psi_i$ superposition, where a is measurements, and ψ is the sum of wave functions, the ψ_i eigenfunction describes the different worlds which exist at the same time but do not affect each other. In this connection, the single physical reality described by ψ is divided into many possible worlds. However, the eigenfunctions which describe these possible worlds are state functions which relate to a person's subjective (not objective) state. Therefore, the reduction $\psi\rightarrow\psi_i$ can only be subjective. That is, these worlds are unique to that person, subjective, and of the mind.

According to Everett's interpretation, the universal wave function is determinist. That is, God does play dice, and he even loads the dice. According to this, all the results of an infinite number of possibilities exist in parallel universes and they are all real, and the universe is divided into the same number of parallel realities as there are alternative results. An observer sees all the results and the observer is also inside a superposition of the different states. In place of collapse with measurement, microscopic superpositions quickly turn into macroscopic superpositions (Everett, 1955).

According to the many worlds/minds view of QM, the state of the cat, ignoring the environment, can be defined in this way:

$$W|\text{dead cat}\rangle|\text{I don't know cat dead}\rangle + z|\text{cat alive }\rangle|\text{I don't know cat alive}\rangle$$

where 'don't know' reflects the subjective conscious state which exists in the experimenter. Sometimes too much has been added to what Everett proposed. Everett proposes that all isolated systems evolve according to Schrödinger's equation and that there is no collapse of wave function. How? Let us look at a system with a spin of ½. Along one axis, the spin can be up $|\uparrow\rangle$ or down $|\downarrow\rangle$. Let's say that if the spin is up, the observer is happy |☺⟩, and if he sees it as down, he is unhappy |☹⟩. Let us show the state before measurement as |☺⟩. Measurement is defined by Schrödinger's time-related unitary operator by $U = e^{-iH\tau/\hbar}$. Applied to the system, this can be written:

$$\mathrm{U}|\uparrow\rangle \otimes |\text{😐}\rangle = |\uparrow\rangle \otimes |\text{☺}\rangle \text{ and } \mathrm{U}|\downarrow\rangle \otimes |\text{😐}\rangle = |\downarrow\rangle \otimes |\text{☹}\rangle$$

In order to understand the non-random state of MWI, it is necessary to understand the meaning of the world's 'internal view and 'external view'. The external view is a mathematical way (like the wave function). The internal view is perceived subjectively by the brain from the observer's viewpoint. The internal view is perceived by two opposite measurements: $|\text{☺}\rangle$ and $|\text{☹}\rangle$. But before measurement, it is in the form $|\text{😐}\rangle$ in the observer's mind. The internal view and the observer will recognize the random sequence of superposition as up and down spins. The chance of each result is 0.5, so that MWI exhibits a solid causality with the external view, even though with the internal view it is quite clearly random/probabilistic.

Why then can we not perceive superposition? The fact that it does not answer this question satisfactorily can be seen as a weak point of MWI. Here the decoherence (lack of equilibrium, collapse of superposition) which is the cause of the universe is proposed. Macrosuperpositions are collapsed by the internal viewpoint. This viewpoint of the observer shows difference from the Copenhagen interpretation. The external viewpoint (mathematical structure) is physically real. Our internal view and linguistic makeup is seen as a useful way to describe our own subjective perceptions. According to this, all of physics is at base a mathematical problem. Or if our internal view which is only in our minds is physically real, the outward view and its completely mathematical language only represent a useful approach. For these reasons, MWI shows an important difference between internal and external viewpoints (Tegmark, 1997).

Can communication be established between these separated multiple worlds? According to MWI, each division is thermodynamically irreversible. Events in our minds are also irreversible. Normally, this division would make no difference to us. To choose and to be aware would necessitate our having a mind which could go back. In general belief, we can ascertain other worlds by a mind which can go back. If the worlds are being divided, where is the other world? Why are we not aware of the other worlds? Why do we experience only and always our own world? It is not difficult to answer these questions.

Just as there is no use of the word 'probability' in MWI, there is no 'uncertainty' as an indicator of lack of knowledge either. Differently in the Copenhagen interpretation, it is deterministic until the observer is involved, and the indeterminist structure is shown with the collapse of the wave. Everett's division of the world into two does not mean that they can never interact again. This is both a misunderstanding and not consistent with what Everett proposes. According to MWI, there is and always will be a single wave function. Each of the perceived parallel realities is equally real (Tegmark, 2001).

For each cat in our universe which accepts Schrödinger's equations and which has suffered no collapse of probabilities there is also a cat in another universe for the other possible results. Two universes form, one for the observer who sees the cat as dead and the dead cat, and one for the observer who sees the cat as alive and the living cat. These two universes are within one bigger universe. And as it is accepted that the observer's state of consciousness and mind are divided into two, each observer will exist twice over, and each time he comes into existence he will have different experiences. The whole universe in which the observer lives will divide into two or more universes at each 'measurement'. As a result the branches of the universe are budding and sprouting like crazy. In reality, each choice of possibility will exist at one and the same time. However, each one is unaware of the existence of the others. MWI does not explain why a conscious being is aware only of one of them, and this causes a lot of problems. In addition, it is a very inefficient theory. It necessitates as many universes as there are grains of sand on all the beaches of the world. But we know that the total energy of the universe is finite. According to WMI, each time a choice is made there is another superposition, and this can continue to infinity. In this way it is necessary to think of a universe full of an infinite number of 'true copies', each one identical to it. Thus it does not seem possible that a universe with finite energy sources could support the creation of an infinite number of new universes, of course if there is not creation at every moment.

Even though this may look like fantasy, participants at an international meeting of physicists in 1974 were asked which solution they favoured to the measurement problem, and the Copenhagen interpretation came top of the list, followed by MWI (Tegmark, 1997). Stephen Hawking, Murray Gell-Mann and Richard Feynman answered that they thought MWI was correct, and only Roger Penrose said he did not accept it.

4. Decoherence

There are two questions that Everett's theory cannot answer. The first is that if macroscopic superpositions exist in the world, why we cannot perceive them; and the second is which physical mechanisms select classical final states.

Consciousness has a physical background and basis, and this shows that it can be described using the terminology of physics. Decoherence, or reaching a single result for superposition for environmental reasons is a real physical event and can be examined in physics laboratories. The shift from quantum uncertainty to classical reality happens in the course of quantum measurement, and it is proposed that it may happen because of external effects on the object measured. The measured object is an 'open' quantum system. The way open systems behave is shown by their interaction with the environment. For example, the density matrix (DM) for the superposition state of the quantum playing cards which have been stood up on edge is as follows (Dugic *et al.*, 2002):

$$YM = \begin{pmatrix} a & c \\ c^* & b \end{pmatrix}$$

where the symbols a and b represent the face (*a*) and the back (*b*) sides of the card. Each one has an equal value (*c* and *c**). As a result the density matrix becomes:

$$\begin{pmatrix} a & 0 \\ 0 & b \end{pmatrix}$$

This is a known classic state: if the card is left standing up, it will fall on one side (*a*) or the other (*b*). However it is impossible to know which side it will fall on. The empty corners of the matrix, shown by 0, reflect the quantum uncertainty (*o*) of superposition. In a real coffeehouse the fall of the card to one side or the other may be affected by the movement of the air, the door being left open, the wind, or someone's breath. The same is true for quantum cards, and environmental quantum effects will determine the fall of the card on one side or the other. The card cannot fall on both sides at the same time (*a*+*b*); it must make the choice of falling on one side (*a*) or the other (*b*).

The basic explanation of decoherence is what kind of an interaction the object and the environment enter into and how it translates the states of superposition (*o*) into the classical final state which we perceive (*a* or *b*). If a friend looks at the cards without telling you, then according to the Copenhagen interpretation the *c*'s change by collapse. And according to the concept of decoherence, a human observer is unnecessary for this effect. Photons in the environment in a superposed state reach their classical final state by colliding with air molecules without the presence of an observer with a conscious brain. This explains why we do not see superposition around us. As a result, it is because it is impossible to isolate a macrouniversal object such as a card in the coffeehouse or a cat from the environment that they are not in a superposed state. Microuniversal objects however can easily be isolated from their environment, and thus display quantum behaviour.

The second question which Everett does not answer, of how the classical choice is made, is explained in decoherence theory. Decoherence affects the empty diagonal matrix elements more, and if the density matrix of the card falling on one side is in the state

$$\begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}$$

then the state of the card is certainly face side up. Nevertheless, at the exact moment of decoherence, its state will form a density matrix like this:

$$\begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix}$$

If at that point we try to measure what state the card is in, we will arrive at a random result.

According to decoherence theory, the universe is divided in to three basic parts. Each one expresses a degree of freedom. The universe of classical statistical mechanics is divided into two: the object under observation and everything else (the environment). But in decoherence theory a third element, the subject, is added to this pair. In the application made in this state, the internal dynamics of all subsystems and their interactions are described by Schrödinger's equations and their overall relations are explained.

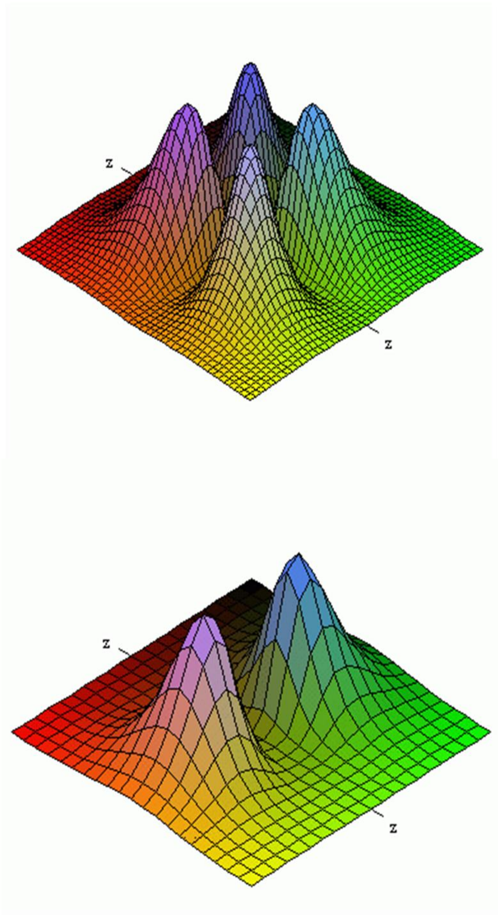

Figure. Density matrices of the wave functions shown graphically. On the left the values are taken as 1-1-1-1, and on the right as 1-0-1-0.

The dynamics of an object are one of the most important. If we think of the playing cards, they can fall either to the right or to the left in the collapsed state. When an observer looks at the card, the subject-object interaction and the mental state will enter a state of superposition, and the bet on whether the card will fall face up or face down will be won or lost. Even so, someone who is schizophrenic in his mind will not be able to notice the superposed state of these two. Decoherence will form quickly, and superposition will become unobservable. In a normal brain, perceptual information processing takes 10^{-3} seconds. According to calculations, the times taken for decoherence to occur is approximately 10^{-20} seconds. Thus the duration of decoherence is much shorter than the time needed for perception. Therefore, we cannot perceive these strange superpositions.

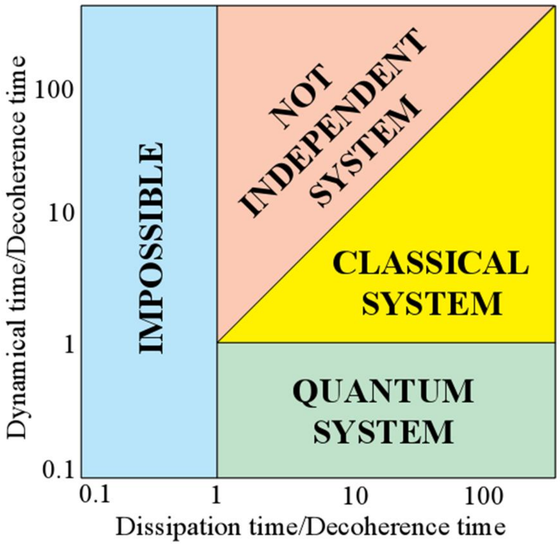

Figure. The interaction which occurs between dissipation and decoherence in various systems. The limits operated by the rules of classical macroscopic = macrouniversal) physics and quantum (microscopic = microuniversal) physics can be seen in this figure. However, these limits are not as clear-cut as shown here (from *Tegmark M., The Importance of Quantum Decoherence in Brain Processes, quant-ph/9907009 v2, 1999*).

5. Wigner's Friend

Eugene Wigner (1902-1995) tries to find this difference by asking what are the characteristics which describe or separate the cat and the hammer from each other in Schrödinger's cat experiment. The difference between the observer, the cat and the hammer cannot be a physical difference. All three are macro objects and are composed of the same materials; only the combination of materials is different. In quantum mechanics, it can be said that there is basically no difference between the biochemical content of the observer and the cat, and the hammer. Then who is different? According to Wigner, the difference is with the conscious and informed observer. The cat, the hammer and the radioactive material are devoid of consciousness. The moment a conscious observation takes place, the result of this observation presents us with only one of all the possible and probable states contained in the superposition as a reality.

Eugene Wigner proposes that consciousness is perhaps an undiscovered hidden variable of the cat. According to Wigner, *"It seems almost impossible to explain the laws of quantum theory in a* *consistent way without a reference to consciousness."* According to this, a theory must certainly be formed in which human consciousness is mentioned. Whatever we look at or observe, because of the act of conscious observation, the thing which we are looking at, whether this has happened before or not, splits into choices.[7]

In this interpretation Wigner has an imaginary friend. He is holding the box which contains Schrödinger's cat, and he is in a room. This person, Wigner's friend, is able to decide to look into the box to see the result, and he will be able to decide whether the cat is alive or dead. If the friend does not tell him the state, even though he has looked at the cat, Wigner cannot know whether he is in a happy state at seeing the cat alive, or in an unhappy state at seeing the cat dead. According to the Copenhagen interpretation, until Wigner looks, a decision cannot be made about the friend's state. According to the many worlds-many minds view, the friend and the cat exist in two different universes (Wolf, 1988).

6. The Observer Theory

Evan Harris Walker takes up Wigner's ideas in principle and gives a determining emphasis to the observer and neurological processes in measurement. However, at this point he makes use of the idea of the hidden variable in QM. Hidden variables are themselves consciousness and are not local. That is, they are independent of place and time. Because of this independence, the possibility arises of the neurophysiological processes in the brain having contact with externally located quantum mechanical processes. On this basis, he suggests that the physical rules of operations of nerve synapses take place at the same level in terms of size as QM processes. He states that the connecting link between consciousness and the brain's information-processing processes lies in this relationship.

Calculating the information carried by the optic nerve, Walker suggests that a certain amount of the consciousness of the person observing forms an information flow. A very small part of this (10 bits/sec) is in connected with external quantum processes via non-local hidden parameters. It is possible to say that this quantity of information is hidden in the superposed states of the states which the observing and observed objects enter at the moment of observation. However, since Walker's model only takes account of the amount of knowledge transfer of the optic nerve, the model does not say much about the meaning and importance of the knowledge transferred.

7. Objective Reduction

Well then, why do our senses not allow us to perceive macroscopic superposition? At small scales, quantum theory is determinate and highly accurate. The use of Schrödinger's equation is necessary and depends on the principle of detminateness. This determinateness at the quantum level is designated as U (unitary). The most important characteristic of U is that it is linear. Determinateness is removed only when measurement is made, when it moves from the quantum level to the classic level.

Accepting that wavefunctions are physically real, Penrose believes that things can exist in more than one place at one time. In his opinion, a macroscopic system, like a human being, cannot exist in more than one place for a measurable time, as the corresponding energy difference is very large. A microscopic system, like an electron, can exist in more than one location forever, unless the energy difference becomes large enough (Penrose, 2007);

> "In Einstein's theory, any object that has mass causes a warp in the structure of space and time around it. This warping produces the effect we experience as gravity. Penrose points out that tiny objects, such as dust specks, atoms and electrons, produce space-time warps as well. Ignoring these warps is where most physicists go awry. If a dust speck is in two locations at the same time, each one should create its own distortions in space-time, yielding two superposed gravitational fields. According to Penrose's theory, it takes energy to sustain these dual fields. The stability of a system depends on the amount of energy involved: the higher the energy required to sustain a system, the less stable it is. Over time, an unstable system tends to settle back to its simplest, lowest-energy state: in this case, one object in one location producing one gravitational field. If Penrose is right, gravity yanks objects back into a single location, without any need to invoke observers or parallel universes."

Penrose proposes that QM is deficient and we need to add something that we do not yet have to the standard rules, and suggests that what he calls Objective Reduction (OR) of the wave function will close this gap. This can be seen as the word "or". "Or" is both meaningful for OR and fits the content of what it wants to express. It enables the choice of the realization of one *or* the other of the superpositions. The OR process means the collapse of the reduction of the vector of a state or the wave function. In OR, only one of the choice of measurement of observation remains standing. Only at this stage does the lack of determinateness of quantum theory come in, and superposition appears at the level of space-time. This is the level of Planck length-time. Two space-times (dead cat or living cat) separate from one another. In the state of a separation in space-time in Planck measurement, a small spatial separation means a long time, and a large spatial separation means a shorter time. When nature separates the space-time of two choices, it follows a set of rules.

How long does this separation take to occur? In the period of about a Planck time (10^{-43} sec) the superposition collapses into one state or the other. The time needed for the reduction of this state from two to one / for it to come out to the classic level at the Planck length (10^{-33} cm) and in the Planck time is $T=\hbar/E$, where T is the time needed and E is gravitational energy. In this equation, the time for the collapse of the superposition of an atomic nucleus is 10^8 years, for a proton it is several million years, for something of 10^{-5} cm in size it is 2 hours, for 10^{-4} cm it is 1/10 sec, and for 10^{-3} cm the collapse time is 10^{-6} sec. That is, as the mass increases, the reduction time is shortened. It is for this reason that we cannot see the superposition state of macroscopic objects.

8. Poincaré Resonances

Ilya Prigogine did not find the various approaches to solving the measurement problem convincing, saying

> "Ordinary disturbances from the environment will upset the quantal characteristics of the wave system and thus will be held responsible for measurement. However, what does the 'environment' theory express? Who differentiates between an object and its environment?"

According to Prigogine, there is a separate characterization in wave function terms and a statistical characterization with probability dissipation terms. On the one hand is Schrödinger's deterministic and symmetrical equation, like Newton's equation which explains the wave function; on the other it explains the asymmetric collapse of the wave function connected to the measurement process. This is a strange construct. For this reason, something new must be brought in and because there is symmetry at the heart of the measurement process, it clashes with QM. This is because QM does not accommodate asymmetric processes. For this reason it resembles classical mechanics. Prigogine proposes that there will be a solution of the application to QM of instability relating to Poincaré resonances. In this condition, the basic object of QM is no longer the ψ wave function but the ρ probability of classical mechanics, also known in QM as the density matrix. ρ probability distribution (q, p, t) is related to both spatial location (q) and momentum (p). Prigogine indicates that locations can be written as $\psi_{(q)}$, and momentums as $\psi_{(p)}$. However, the uncertainty principle which is a basic rule of QM prevents their use at the same time with the same precision. The quantum state of ψ shows the amplitude of probability and a transition may be made from probability amplitudes to actual probabilities. In this way the measurement problem in QM is removed, and there is no further need for the reduction of the wave function. The observer plays no special role. The basic size is not probability amplitude but probability itself, and the means of measurement shows broken time symmetry (Stengers and Prigogine, 1997).

Result

As can be seen from all these approaches, there remains an unresolved problem of measurement in QM. Looking at these past and present arguments, it can be seen that this is not an artificially created problem, which seems insoluble without the addition of the consciousness of an observer or the insertion of consciousness variables into the equation. Once we develop and understand these equations, our understanding of the universe will undergo a revolutionary change.

Table. The Measurement problem in quantum mechanics: various solutions and characteristics. The most common interpretations are summarized in the table below. The values shown in the cells of the table are not without controversy, for the precise meanings of some of the concepts involved are unclear and, in fact, are themselves at the centre of the controversy surrounding the given interpretation. No experimental evidence exists that distinguishes among these interpretations. To that extent, the physical theory stands, and is consistent with itself and with reality; difficulties arise only when one attempts to "interpret" the theory. Nevertheless, designing experiments which would test the various interpretations is the subject of active research. Most of these interpretations have variants. For example, it is difficult to get a precise definition of the Copenhagen interpretation as it was developed and argued about by many people.

Interpretation	Author(s)	Deterministic?	Wavefunction real?	Unique history?	Hidden variables?	Collapsing wavefunctions?	Observer role?	Local?
Ensemble interpretation	Max Born, 1926	Agnostic	No	Yes	Agnostic	No	None	No
Copenhagen interpretation	Niels Bohr, Werner Heisenberg, 1927	No	No[1]	Yes	No	Yes[2]	None	No
de Broglie-Bohm theory	Louis de Broglie, 1927, David Bohm, 1952	Yes	Yes[3]	Yes[4]	Yes	No	None	No
von Neumann interpretation	von Neumann, 1932, Wheeler, Wigner	No	Yes	Yes	No	Yes	Causal	No
Quantum logic	Garrett Birkhoff, 1936	Agnostic	Agnostic	Yes[5]	No	No	Interpretational[6]	Agnostic
Many-worlds interpretation	Hugh Everett, 1957	Yes	Yes	No	No	No	None	Yes
Popper's interpretation[35]	Karl Popper, 1957[36]	No	Yes	Yes	Yes	No	None	Yes
Time-symmetric theories	Yakir Aharonov, 1964	Yes	Yes	Yes	Yes	No	No	
Stochastic interpretation	Edward Nelson, 1966	No	No	Yes	No	No	None	No
Many-minds interpretation	H. Dieter Zeh, 1970	Yes	Yes	No	No	No	Interpretational[7]	Yes
Consistent histories	Robert B. Griffiths, 1984	Agnostic[8]	Agnostic[8]	No	No	No	Interpretational[6]	Yes
Objective collapse theories	Ghirardi-Rimini-Weber, 1986	No	Yes	Yes	No	Yes	None	No
Transactional interpretation	John G. Cramer, 1986	No	Yes	Yes	No	Yes[9]	None	No
Relational interpretation	Carlo Rovelli, 1994	No	Yes	Agnostic[10]	No	Yes[11]	Intrinsic[12]	Yes

[1] According to Bohr, the concept of a physical state independent of the conditions of its experimental observation does not have a well-defined meaning. According to Heisenberg the wavefunction represents a probability, but not an objective reality itself in space and time.

[2] According to the Copenhagen interpretation, the wavefunction collapses when a measurement is performed.

[3] Both particle AND guiding wavefunction are real.

[4] Unique particle history but multiple wave histories.

[5] But quantum logic is more limited in applicability than Coherent Histories.

[6] Quantum mechanics is regarded as a way of predicting observations, or a theory of measurement.

[7] Observers separate the universal wavefunction into orthogonal sets of experiences.

[8] If wavefunction is real then this becomes the many-worlds interpretation. If wavefunction less than real, but more than just information, then Zurek calls this the "existential interpretation"

[9] In the TI the collapse of the state vector is interpreted as the completion of the transaction between emitter and absorber.

[10] Comparing histories between systems in this interpretation has no well-defined meaning.

[11] Any physical interaction is treated as a collapse event relative to the systems involved, not just macroscopic or conscious observers.

[12] The state of the system is observer-dependent, i.e., the state is specific to the reference frame of the observer.

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