In quantum mechanics, there are two essentially different ways in which the state of a system changes, one continuous and causal, and the other discontinuous and probabilistic. Let \( \psi \) be the state of a system with energy operator \( H \), then the two processes are:

1. The discontinuous change brought about by the measurement of a quantity \( q \) with operator \( R \) and eigenstates \( \phi_n \) upon the state \( \psi \). In this case the state \( \psi \) will be changed to the state \( \phi_1 \) with probability \( a_i a_j \) where the \( a_i \) are the expansion coefficients of \( \psi \) in terms of the \( \phi_i \): \( \psi = \sum a_i \phi_i \).

2. The continuous, causal change of the state of the system with time generated by the energy operator:

   \[
   \psi_t = e^{-iHt} \psi_0
   \]

The question arises as to whether these two rules are compatible; in particular what occurs in the event that rule 2 is applied to the measurement process itself (i.e., to the state of the combined system of original system plus apparatus and observer). In this case nothing like the discontinuity of rule one can occur, and one has to decide whether to abandon (1), and the statistical interpretation of quantum mechanics in favor of the purely causal description (2), or to limit the applicability of (2) only to systems in which measurements are not taking place. If we were to deny the applicability of (2) to the measurement process, however, we are faced with the immediate difficulty of how to distinguish a measurement process from other natural processes. For what might a group of some particles be construed as forming a measuring apparatus, and cease to be governed by (2)?

We would be faced with the task of dividing all processes into two types, the usual ones which are governed by (2), and the mysterious type called measurements which are immune to (2) and only follow (1).

It is the purpose of this note to indicate that one can successfully interpret a model which postulates some sort of universal state function (wave function), and in which only rule 2 is valid, in such
a way that rule 1 appears to hold, that is, holds subjectively to an observer. We wish to show that a completely causal theory is quite adequate which, on the other hand, leads to an apparently probabilistic world on a subjective level in a rather novel way.

The essence of this theory is the abandonment of the concept of the uniqueness of observers, i.e., that there are individual entities, machines, people, etc., which remain single unique individuals throughout periods of time. In this theory when measurements (or in general any observations) are made on systems by "observers" (by which we mean merely other systems) the observer itself splits into a number of observers, each of which sees a definite result for the state of the system.

Now, all of this, which is seemingly quite farfetched and contrary to our experience, is actually implied if one takes seriously the formalism of wave mechanics (without rule one) and we shall even see that we can recover rule one from this picture as a tool of practical expediency, not as a basic hypothesis.

We turn now to the formalism of quantum mechanics. We shall assume a particle model, in which we envisage the universe to be composed of a large number of elementary particles, possessing a single total wave function, which we assume to obey the Schrödinger equation. (No results will depend upon this, however, they will hold for field theories as well, and any wave equations, i.e., any system of "quantum mechanics").

The first question that arises is "what actually does happen in the process of measurement?" Several authors (Von Neumann, Bohm, etc.) treat this question to some degree, and assume an abstract model which consists of a system, $S$, and a measuring apparatus $A$. We assume that the system variable of interest is $x$, and that the apparatus variable of interest is $y$ (position of meter needle, spot of photographic film, etc.) and that prior to making a measurement the system is in a definite state $\psi_s^0$ and the apparatus in a state $\psi_a^0$, and furthermore that they are initially independent, so that the wave function of the whole system before the measurement begins is simply the product $\psi_s^0 \psi_a^0$.

$$\psi_{s+A}^0 = \psi_s^0 \psi_a^0$$
The measurement is then brought about by allowing the two systems to interact, i.e. by "turning on" a suitable Hamiltonian $H_I(x,y)$ which is chosen so as to introduce a correlation between the system variable $x$ and the apparatus variable $y$. However, in order that the measurement be "good", the system state must not be disturbed if (except in phase) if it is an eigenstate of the measurement.

Now, the measurement is arranged so that corresponding to each system state (eigenstate) $x_i$ will be a definite apparatus state $y_i$ after the measurement. However, if the system is originally not in a definite eigenstate $x_i$ but a state of the form $\psi = \sum_i a_i \psi_i$, where the $\psi_i$ are eigenstates for $x$ then after the measurement the apparatus will also not be in a definite $y$ state, but will have as its state $\sum_i a_i u_i(y)$ where the $u_i$ are the eigenstates of $y$. This follows from the linearity of the wave equation and the superposition principle.

In short, nothing discontinuous has happened, the system has not been forced to jump into an eigenstate, and, indeed, the relative amplitudes for the various eigenstates has not even changed. How can it be that Rule 1 is an adequate description? Even so, however, the apparatus has become correlated to the system, while neither $x$ nor $y$ is in a definite state of the variable under discussion (reminiscent of the example of Einstein, Rosen & Podolski).

This is possible since after the measurement the wave function for $S+A$ is in a higher dimensional space than that of $S$ or $A$ alone, i.e. if we look at a "cross section" of the total wave function for which the variable $x$ has definite value $x_i$, we find that the apparatus has the definite value $y_i$ which corresponds, while if we choose to consider the cross section for $x_j$ definite, we immediately find that $y$ has the definite value $y_j$, etc.

So we see that from the viewpoint of quantum mechanics that when a measuring apparatus interacts with a system which is not in an eigenstate of the variable being measured that the apparatus itself "smears out" and is indefinite, no matter how large or "classical" it is. Nevertheless, it is correlated with the system in the above sense, and it is this correlation which saves the day and allows us to construct an adequate theory.
How is it possible, this 'smearing out' of even classical objects which is implied by quantum mechanics, and which is seemingly so contrary to our experience? Does this mean that we must abandon our quantum mechanical description and say that it fails at a classical level? Not at all. All we have to do is carry the theory to its logical conclusion to see that it is all right after all.

Suppose a human observer sets up his apparatus and makes a measurement on a system not in an eigenstate of the measurement, the result to appear as the position $x$ of a meter needle. According to what we have said the meter needle itself will be "smeared out" after the measurement, but correlated to the system. Why doesn't our observer see a smeared out needle? The answer is quite simple.

He behaves just like the apparatus did. When he looks at the needle (interacts) he himself becomes smeared out, but strongly correlated to the apparatus, and hence to the system. If we for a moment reflect upon the total wave function of the situation system-apparatus-observer, and again consider "cross sections" we see that for the definite value $x_j$ for the system the needle has definite position $y_j$, and there is a definite observer who perceived that the needle had the definite position $y_j$, and, of course, similarly for all other values. In other words, the observer himself has split into a number of observers, each of which sees a definite result of the measurement.

We now see that the quantum mechanical description is really compatible with our ideas of definiteness on a classical level, due to the existence of strong correlations. This is the reason for the apparant existence of a classical world.
We must now turn around and try to see why rule 1 has been so successful. Imagine an observer making a series of quantum mechanical measurements (such as the sequence of measuring the z component of spin of an electron, then its x component, then again its z component, etc.). From the point of view of wave mechanics he is splitting each time a measurement is made, so that after a number of measurements we could speak of his "life tree". If we focus our attention on any single "track" of this tree we see an observer who always perceives definite (and unpredictable) results of his measurements, and to whom the system has, with each measurement, apparently popped discontinuously into an eigenstate of the measurement. (Whereas from our point of view the observer himself has simply split into a number of observers, one for each eigenstate of the system, a process which is quite continuous and causal from the overall point of view. Furthermore, for almost all of the "tracks" which we might consider, the frequencies with which the observer sees the various results will follow the probabilistic law of rule 1. Therefore, for practical considerations any observer should use rule 1 for calculations, not because the system undergoes any such probabilistic jumps but simply because he himself will split into a number of observers, to each of which it appears that the system underwent probabilistic jumps.

We have, then, a theory which is objectively causal and continuous, while at the same time subjectively probabilistic and discontinuous. It can lay claim to a certain universality, since it applies to all systems, of whatever size, and is still capable of explaining the classical appearance of the macroscopic world.
The price, however, is the abandonment of the concept of the uniqueness of the observer, with its somewhat disconcerting philosophical implications.

As an analogy one can imagine an intelligent amoeba with a good memory. As time progresses the amoeba is constantly splitting, each time the resulting amoebas having the same memories as the parent. Our amoeba hence does not have a life line, but a life tree. The question of identity or non identity of two amoebas at a later time must be rephrased. At any time we can consider two of them, and they will have common memories up to a point (common parent) after which they will diverge according to their separate lives after this point. It becomes simply a matter of terminology as to whether they should be thought of as the same amoeba or not, or whether the phrase "the amoeba" should be reserved for the whole ensemble.

We can get a closer analogy if we were to take one of these intelligent amoebas, erase his past memories, and render him unconscious while he underwent fission, placing the two resulting amoebas in separate tanks, and repeating this process for all succeeding generations, so that none of the amoebas would be aware of their splitting. After awhile we would have a large number of individuals, sharing some memories with one another, differing in others, each of which is completely unaware of his "other selves" and under the impression that he is a unique individual. It would be difficult indeed to convince such an amoeba of the true situation short of confronting him with his "other selves".
The same is true of one accepts the hypothesis of the universal wave function. Each time an individual splits he is unaware of itself, and any single individual is at all times unaware of his "other selves" with which he has no interaction from the time of splitting.

We have indicated that it is possible to have a complete, causal theory of quantum mechanics, which simultaneously displays probabilistic aspects on a subjective level, and that this theory does not involve any new postulates, but in fact results simply by taking seriously wave mechanics and assuming its general validity. The physical "reality" is assumed to be the wave function of the whole universe itself. By properly interpreting the internal correlations in this wave function it is possible to explain the appearance of the world to us (classical physics, etc.), as well as the apparent probabilistic aspects.