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Collapse of the State Vector and Psychokinetic Effect

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Eugene Wigner and others have speculated that the "collapse of the state vector" during an observation might be a physically real process so that some modification of current quantum theory would be required to describe the interaction with a conscious observer appropriately.

Experimental reports on the "psychokinetic effect" as a mental influence on the outcome of quantum jumps suggest that perhaps this effect might be vital for an understanding of the observer's role in quantum mechanics.

Combining these two speculations we introduce a reduction principle that provides for the gradual reduction of a macroscopically ambiguous state and allows simultaneously for the occurrence of some psychokinetic effect in the process of observation.

The resulting model leads to many of the paradoxical, but logically consistent, features of the psychokinetic effect that have been reported, and makes further testable predictions.

The model does not touch on the more profound questions of consciousness. But the model implies that the result of a conscious observation, the collapse of the state vector, becomes accessible to the experimenter, with the psychokinetic effect as probe: Whether Schrödinger's cat has not or has collapsed the state vector determines whether or not the later human observer can still exert a psychokinetic influence on the result.

1. INTRODUCTION

Consider the case of a binary quantum decision that leads to two possible macroscopically different outcomes. Take as a typical example an indeterministic binary random event generator[(1)] that, after triggering, selects randomly a red or a green lamp to be lit.

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If, before the triggering, the system can be described by a state vector, then after the triggering this state vector

$$\xi\rangle = a\xi_1\rangle + b\xi_2\rangle \quad \text{with} \quad \langle\xi \mid \xi\rangle = \langle\xi_1 \mid \xi_1\rangle = \langle\xi_2 \mid \xi_2\rangle = 1 \tag{1}$$

appears as the superposition of the two macroscopically different states $\xi_1\rangle$ and $\xi_2\rangle$ where the red or green lamp is lit, respectively. We say that the state vector $\xi\rangle$ is macroscopically ambiguous.

The occurrence of macroscopically ambiguous states has led to much controversey because we seem to observe subjectively only macroscopically sharp states and never the "superposition" of two or more macroscopically different states. In spite of this still ongoing discussion about the proper interpretation of quantum theory,[2,3] there is largely agreement on the practical aspects of the matter:

We can use Schrödinger's equation as long as no observation is made, and calculate "as if" the observation would induce a random "jump" of the state vector $\xi\rangle$ into the macroscopically sharp vectors $\xi_1\rangle$ or $\xi_2\rangle$ with the probabilities aa^* and bb^*, respectively. This corresponds to a "reduction" of the density matrix from

$$\rho = \xi\rangle\langle\xi = aa^*\xi_i\rangle\langle\xi_1 + ab^*\xi_1\rangle\langle\xi_2 + ba^*\xi_2\rangle\langle\xi_1 + bb^*\xi_2\rangle\langle\xi_2 \tag{2}$$

to the reduced matrix

$$\rho' = aa^*\xi_1\rangle\langle\xi_1 + bb^*\xi_2\rangle\langle\xi_2 \tag{3}$$

It may appear reasonable to see this reduction as a transition from an undecided situation into a physically real state where nature has made up her mind for one or the other outcome. But, surprisingly, the formalism of quantum theory does not account for this transition, but rather refers to a somewhat elusive external observer to define physical reality. Certainly quantum theory is logically self consistent. And the inability of the formalism to define an absolute reality may convey to us some profound truth about nature and its observers.

But still, we might want to look for other less extreme formulations of quantum theory, more in accordance with our individually colored feelings of plausibility. There we may aim in one of two directions: We may either try to reformulate the theory such that no macroscopically ambiguous states do arise and the human observer plays no more crucial a role than other recording equipment, or we may accept the singular role of the human observer.

The feeling that the human observer or human "consciousness" plays a singular role in quantum theory has already been expressed by the early pioneers in the field.[4]

Most specifically, Wigner[5] championed the idea that it is human consciousness that causes the collapse of the state vector, whereas in the absence of observers conventional quantum theory, even with its macroscopically ambiguous states, is valid. In the following we will pursue this idea.

The use of the term "consciousness" in this context may be somewhat pretentious. There are certainly no claims that our studies should shed light on the profound problems of consciousness as raised by Buddhist meditators or other thinkers.

The hypothesis that it is the act of observation that collapses the state vector seems not accessible to verification because the two density matrices of (2) and (3) lead in quantum theory to the same expectation values for all possible experiments. But if the validity of quantum theory were suspended in the act of observation, Wigner argues, this might have observable implications.

Experimental indications that human consciousness might do even more than collapse state vectors comes from rather extensive laboratory work in parapsychology. Let me mention here in particular the experiments on the "psychokinetic effect" (PK). The first reports on this effect came from Louisa and J. B. Rhine,[6,7] based on experiments in which human subjects tried to affect the outcome of dice falls. These early experiments have been, rightly or wrongly, much criticized. The basic finding, however, that the human will can under certain conditions affect the outcome of random processes was apparently confirmed by many later researchers working under more sophisticated test conditions. After John Beloff[8] had pointed out that the ideal targets for the mental effort in a PK experiment should be indeterministic quantum jumps, Chauvin and Genthon[9] reported positive results from experiments where highly motivated teenagers tried to slow down or speed up the counting rate of a Geiger counter exposed to a weak radioactive source. Subsequently I reported a large number of experiments[10,11] in which human subjects were apparently able to affect the decisions made by quantum mechanical (indeterministic) random number generators. These experiments emphasised, apart from the existence of a PK effect, the independence of the effect of space, time, complexity and similar factors that would limit the effectiveness of the conventional physical "forces". The most recent, statistically astronomically significant confirmation of PK action on an indeterinistic random number generator was reported by R. G. Jahn and B. Dunne.[12]

Unfortunately even the most successful workers in this field have to agree that the experiments are still rather tedious and time consuming: First, the effects are small so that many trials are needed for statistical significance. Second, only some selected subjects perform reasonably well, but even there the experimenters have to work very hard to keep the subject's interest and motivation alive for the often strenuous or even painful mental effort required for success. This situation may change with more skilled experimenters getting involved, but, in the meantime, it may explain why only few of the challenging questions raised in the following have so far been studied experimentally.

The reader may wonder whether it is reasonable at this stage to theorize much about the PK mechanism before experimenters have managed to get the effect under better control. But with an effect so paradox, so contrary to everyday intuition, it is vital to have some self consistent model theories in order to design systematic experiments.

Considering the reported "nonlocal" or in some sense even "noncausal" features[13] of the PK effect one might base a PK model on some explicitly noncausal mechanism, quite independent of the quantum mechanics. One such model has been reported previously.[14] But this particular model seemed limited in its usefulness by the occurence of some "divergence problem".

The first attempt to link the PK problem explicitly with basic questions of quantum theory was made by Walker[15] who based his discussion on hidden variable theories. Later some of these ideas were clarified and extended by Mattuck,[16] using the Bohm–Bub hidden variable theory. In this model the mind can affect the hidden variables which in turn determine the outcome of the random processes of quantum theory. This idea seems attractive insofar as the hidden variables have already some nonlocal features so that, naively speaking, the mind grabbing and changing a hidden variable could produce observable effects at some distant location.

In the following we will not use hidden variables but rather study how the Schrödinger equation might be modified in the most simple manner such as to allow for a PK effect and an automatic reduction of the state vector under an observation.

The next two sections serve as preparation for sec. 4 where we introduce the reduction equation that provides for a smooth reduction of the state vector in the process of observation. The reduction principle will leave room for a psychokinetic effect so that, for example, the state of (2) may get reduced into a mixture

$$\rho' = p'\xi_1\rangle\langle\xi_1 + q'\xi_2\rangle\langle\xi_2 \tag{3'}$$

where the coefficients p' and q' may be different from aa^* and bb^* in (3).

2. BINARY OBSERVATION AND ASSOCIATED MACROSCOPIC PROJECTION OPERATOR

Consider first a binary observation where the observer can distinguish only two possible outcomes, like the lighting of a red or a green lamp. After one of the lamps has been lit, but before the observer has become consciously aware of the result, we can write the state vector (1) as

$$\xi\rangle = a\xi_1\rangle + b\xi_2\rangle = Q\xi\rangle + \bar{Q}\xi\rangle \tag{4}$$

with

$$\bar{Q} = 1 - Q \tag{5}$$

Here $\xi_1\rangle$, $\xi_2\rangle$ are states with the red or green lamp lit, respectively, and $Q, \bar{Q}$ are the projection operators into the subspaces of all states with red or green lamp lit. (We are assuming an arrangement where the triggering of the binary random generator causes exactly one lamp to light.) The operators $Q, \bar{Q}$ satisfy

$$Q^2 = Q = Q^+, \quad \bar{Q}^2 = \bar{Q} = \bar{Q}^+, \quad Q\bar{Q} = \bar{Q}Q = 0 \tag{6}$$

More complex observations may be considered as a superposition of many binary observations with their associated projection operators.

3. STATE MIXTURES

If a system can be described by a single normalized state vector $\xi\rangle$ with the corresponding density matrix

$$\eta = \xi\rangle\langle\xi \tag{7}$$

then

$$\langle\xi \mid \xi\rangle = \mathbf{Tr}(\eta) = 1, \qquad \eta^2 = \eta \tag{8}$$

We will call any matrix η of this form a pure state density matrix or pure state projection operator.

Consider next an ensemble of possible state vectors $\xi_i\rangle, \cdots \xi_N\rangle$ where $\xi_i\rangle$ occurs with the probability P_1.

We will write this ensemble as a weighted "mixture" of pure state projection operators

$$\mu = P_1\eta_1 \oplus P_2\eta_2 \oplus \cdots \oplus P_N\eta_N = \operatorname*{Mix}_{i=1}^{N} P_i\eta_i \tag{9}$$

with

$$\eta_i = \xi_i\rangle\langle\xi_i, \qquad \mathbf{Tr}(\eta_i) = 1 \tag{10}$$

We call the mixture normalized if

$$\text{Norm}(\mu) = \sum_{i=1}^{N} P_i = 1 \tag{11}$$

The $\oplus$ symbol in (9) indicates the inclusion of the following state with its statistical weight into the mixture; it does not indicate an algebraic addition of the matrices. The last expression in (9) is simply a shorthand notation for the preceeding expression.

An algebraic addition of the terms in (9) leads to the density matrix

$$\rho = \sum_{i=1}^{N} P_i \eta_i \tag{12}$$

In conventional quantum theory the density matrix alone tells us all there is to known about the system, i.e., we may forget the individual states from which the mixture originated. In the following formalism, however, this is not quite true: sometimes we have to remember more about the mixture than the sum of (12).

We can define the "sum" of two mixtures

$$\mu_+ = \mu_1 \oplus \mu_2 \tag{13}$$

by merging the two ensembles where, however, members corresponding to the same state can be combined, i.e.,

$$A\xi_1\rangle\langle\xi_1 \oplus B\xi_1\rangle\langle\xi_1 = (A+B)\,\xi_1\rangle\langle\xi_1 \tag{14}$$

A "difference" between two mixtures

$$\mu_- = \mu_1 \ominus \mu_2 \tag{15}$$

may be defined if all members of μ_2 are contained in μ_1 with smaller or equal weights.

In the following we will often want to leave the number of elements in a mixture open. Then it is convenient to write the mixture in (9) in the form

$$\mu = \operatorname*{Mix}_{\eta} P(\eta)\eta \tag{16}$$

where the mixture is extended over all represented pure state density matricies η.

4. REDUCTION PRINCIPLE

Now we want to formulate a general reduction equation that can gradually reduce the density matrix of (2) into the form of (3′). Considering a binary observation with projection operator Q, the reduction process may depend on the particular observer. We will use in our model two parameters, κ and ε to describe the functioning of the observer in a particular binary observation. The nonnegative parameter κ measures the speed of the reduction process. We will call κ the "alertness parameter" in agreement with the intuitive feeling that a highly alert observer might produce a faster collapse of the state vector than a sleepy one. The other parameter ε, the "PK coefficient" measures the strength of the associated psychokinetic effect. This parameter can be positive or negative corresponding to an increased probability for one or the other outcome of the binary decision. We may expect that for a given observer the parameters κ and ε change with time and depend in a rather subtle manner on his momentary mental state.

In the following I will use a Heisenberg representation where the density matrix of the conventional formalism is constant in time. Then I postulate a "reduction principle" that, under the influence of an observation, may break up a pure state density matrix into a mixture of other pure state density matrices as follows:

We write the state at time t as a mixture of pure state density matrices

$$\mu(t) = \operatorname*{Mix}_{\eta} P(t, \eta)\eta \tag{17}$$

Here the matrix η plays the role of a summation parameter and is a normalized pure state density matrix (see Equations 9 and 16), i.e.

$$\eta^2 = \eta, \qquad \mathbf{Tr}(\eta) = 1 \tag{18}$$

For the change of $\mu(t)$ under an observation we now postulate the reduction equation

$$\frac{\partial}{\partial t}\mu(t) = \operatorname*{Mix}_{\eta} \left\{ \begin{matrix} \ominus\kappa\eta \oplus [\kappa + \varepsilon\, \mathbf{Tr}(\eta\bar{Q})]\, Q\eta Q \\ \oplus [\kappa - \varepsilon\, \mathbf{Tr}(\eta Q)]\, \bar{Q}\eta\bar{Q} \end{matrix} \right\} P(t, \eta) \tag{19}$$

Note that $\mu(t + dt)$ appears again as a superposition of pure state density matrices and that the reduction equation conserves the norm of $\mu(t)$ (see Equation 11) so that we may assume that

$$\text{Norm}(\mu(t)) = \sum_{\eta} P(t, \eta) = 1 \ \text{ for all times} \tag{17a}$$

The reduction equation (19) can be naturally generalized to the case where we have several simultaneous observations with projection operators

Q_s and parameters κ_s, ε_s by extending the mixture over an additional parameter s.

$$\frac{\partial}{\partial t}\mu(t) = \operatorname*{Mix}_{\eta, s} \left\{ \begin{array}{r} \ominus\kappa_s\eta \oplus [\kappa_s + \varepsilon_s \,\mathbf{Tr}(\eta\bar{Q}_s)]\, Q_s\eta Q_s \\ \oplus [\kappa_s - \varepsilon_s \,\mathbf{Tr}(\eta Q_s)]\, \bar{Q}_s\eta\bar{Q}_s \end{array} \right\} P(t, \eta) \tag{19a}$$

In the absence of a PK effect, when $\varepsilon = 0$, the precedding formalism could be much simplified. We could stay in the framework of the conventional density matrix formalism and would not have to introduce mixtures linked by the $\oplus$ operation: For $\varepsilon = 0$ Equation (19) reads

$$\frac{\partial}{\partial t}\mu(t) = \operatorname*{Mix}_{\eta} \kappa[\ominus\eta \oplus Q\eta Q \oplus \bar{Q}\eta\bar{Q}] \tag{19$'$}$$

Introduction the density matrix corresponding to $\mu(t)$ (see Equation 12)

$$\rho(t) = \sum_{\eta} P(t, \eta)\eta \tag{20a}$$

we can rewrite Equation (19′) as an equation for the density matrix

$$\frac{\partial}{\partial t}\rho(t) = -\kappa\rho(t) + \kappa[Q\rho(t)Q + \bar{Q}\rho(t)\bar{Q}] \tag{20b}$$

This equation describes the exponential decay of the "mixed" elements (elements linking the two macroscopically different states) in the density matrix under an observation.

If there is a PK effect, $\varepsilon \neq 0$, then we can no longer reduce (19) into an equation of motion for the density matrix alone because then (19) contains elements quadratic in η. Then we have to use the more detailed formalism with mixtures.

To give an example, let us integrate (19) for the case of a binary observation with the initially pure state

$$\mu(0) = \eta = \xi\rangle\langle\xi \tag{21}$$

where $\xi\rangle$ is the state vector from (1).

Let us write again

$$\begin{aligned} Q\xi\rangle &= a\xi_1\rangle, \qquad \langle\xi_1 \mid \xi_1\rangle = 1 \\ \bar{Q}\xi\rangle &= b\xi_2\rangle, \qquad \langle\xi_2 \mid \xi_2\rangle = 1 \end{aligned} \tag{22}$$

Then we have

$$\mathbf{Tr}(\eta Q) = aa^*, \qquad \mathbf{Tr}(\eta\bar{Q}) = bb^* \tag{23}$$

Now (19) can be solved by the *ansatz*

$$\begin{aligned}\mu(t) &= C(t)\xi\rangle\langle\xi \oplus A(t)\, aa^*\xi_1\rangle\langle\xi_1 \oplus B(t)\, bb^*\xi_2\rangle\langle\xi_2 \\ &= C(t)\eta \oplus A(t)\, Q\eta Q \oplus B(t)\, \bar{Q}\eta\bar{Q}\end{aligned} \tag{24}$$

i.e., during the measurement the initial pure state breaks up into a mixture with only three contributing projection operators, $\eta_0 = \xi\rangle\langle\xi$, $\eta_1 = \xi_1\rangle\langle\xi_1$ and $\eta_2 = \xi_2\rangle\langle\xi_2$.

From (19) and (24) we obtain

$$\begin{aligned}\dot{C}(t) &= -\kappa C(t) \\ \dot{A}(t) &= (\kappa + \varepsilon bb^*)\, C(t) \\ \dot{B}(t) &= (\kappa - \varepsilon aa^*)\, C(t)\end{aligned} \tag{25}$$

or integrated

$$\begin{aligned}C(t) &= e^{-\kappa t} \\ A(t) &= \left(1 + \frac{\varepsilon}{\kappa} bb^*\right)(1 - e^{-\kappa t}) \\ B(t) &= \left(1 - \frac{\varepsilon}{\kappa} aa^*\right)(1 - e^{-\kappa t})\end{aligned} \tag{26}$$

Then the final state (if the observation is completed with unchanged values of κ and ε) is given by

$$\begin{aligned}\mu(\infty) &= \left(1 + \frac{\varepsilon}{\kappa} bb^*\right) aa^*\xi_1\rangle\langle\xi_1 \oplus \left(1 - \frac{\varepsilon}{\kappa} aa^*\right) bb^*\xi_2\rangle\langle\xi_2 \\ &= \left[1 + \frac{\varepsilon}{\kappa} \mathbf{Tr}(\eta\bar{Q})\right] Q\eta Q \oplus \left[1 - \frac{\varepsilon}{\kappa} \mathbf{Tr}(\eta Q)\right] \bar{Q}\eta\bar{Q}\end{aligned} \tag{27}$$

The reduction equation guarantees that the final mixture is normalized. But there is the further requirement we have not yet considered that the coefficients $A(t)$ and $B(t)$ in (26) must always be nonnegative, for all admissible values of aa^* and bb^* ($aa^* + bb^* = 1$, $0 \leqslant aa^* \leqslant 1$). This imposes the restriction

$$|\varepsilon| \leqslant \kappa \tag{28}$$

Note that the final mixture $\mu(\infty)$ in (27) remains unchanged if subsequently the same observation (Q) is repeated by another observer (with parameters κ', ε'). This is easily verified by applying (19) to the mixture of (27).

5. THE PSYCHOKINETIC EFFECT (PK)

Consider again the binary random generator with the red and green lamp. According to conventional quantum mechanics, the probabilities for the red or green lamp to light are ((2) or (27) with $\varepsilon = 0$)

$$p = aa^*, \qquad q = bb^* \tag{29}$$

Under the influence of a PK effect these probabilities are changed (27) to

$$p' = \left(1 + \frac{\varepsilon}{\kappa} q\right) p, \qquad q' = \left(1 - \frac{\varepsilon}{\kappa} p\right) q \tag{30}$$

In the case of a symmetric random generator, $p = q = \frac{1}{2}$, we get

$$p' = \frac{1}{2} + \frac{1}{4}\frac{\varepsilon}{\kappa}, \qquad q' = \frac{1}{2} - \frac{1}{4}\frac{\varepsilon}{\kappa} \tag{31}$$

Here the restriction from (28) limits the maximal average success rate to

$$p'_{\max} = \tfrac{3}{4} = 75\% \tag{32}$$

The actually reported scoring rates are lower; typically, a few percent above the 50% chance scoring rate.

Note that the probabilities p', q' in (30) depend only on the observer parameters κ, ε and on the primary probability values p, q. Apart from that, the success rate of a subject in a PK experiment is in our model independent of the internal structure and the complexity of the indeterministic random generator. This feature, the "complexity independence", seems in agreement with the experimental evidence.[11]

6. A "MACROSCOPIC" EPR EXPERIMENT

In discussing the Einstein-Podolsky-Rosen experiment, one usually considers two microscopic systems A and B that are spatially separated but quantum mechanically correlated. In the framework of conventional quantum theory such an arrangement cannot be used for transmitting information from A to B.

The PK mechanism implied by the reduction equation (19) could change this, however. Take, for example, the case where the systems A and B are two photons in a correlated state

$$\xi_{\text{PHOT}}\rangle = \frac{1}{\sqrt{2}} \{A+\rangle\langle B+\rangle + A-\rangle\, B-\rangle\} \tag{33}$$

where $A+\rangle$, $A-\rangle$, and $B+\rangle$, $B-\rangle$ are two polarisation states for photon A or B, respectively.

Then immediately after an ideal measurement of the polarisation of photon A, the state of the total system (photons plus measuring device) can be written

$$\xi\rangle = \frac{1}{\sqrt{2}} \{\xi+\rangle + \xi-\rangle\} \tag{34}$$

with

$$\xi+\rangle = A+\rangle\, B+\rangle\, S+\rangle, \qquad \xi-\rangle = A-\rangle\, B-\rangle\, S-\rangle \tag{35}$$

where $S+\rangle$ and $S-\rangle$ are states of the measuring device that has macroscopically recorded an $A+\rangle$ or $A-\rangle$ polarisation state of the photon, respectively.

When the human observer becomes aware of the instrument reading, the states $\xi+\rangle$ and $\xi-\rangle$ are eigenstates of the corresponding projection operator Q, so that the final mixture becomes [Eq. (27) with $aa^* = bb^* = 1/2$]

$$\mu(\infty) = \left(\frac{1}{2} + \frac{1}{4}\frac{\varepsilon}{\kappa}\right) \xi+\rangle\langle\xi+ \oplus \left(\frac{1}{2} - \frac{1}{4}\frac{\varepsilon}{\kappa}\right) \xi-\rangle\langle\xi- \tag{36}$$

To transmit a signal from A to B we would need a sufficient number of correlated photon pairs and an observer at A with the PK ability to bias the rate of observed $A+$ events. Then this could be immediately afterwards observed at B as a corresponding bias in the rate of observed $B+$ events, so that we would have an unconventional means for information transmission.(17)

But if our model is right, then this information transmission should work as well when A and B are macroscopic systems. Take as example this arrangement: First a binary random generator is activated to light a red or a green lamp. Next a polaroid color camera takes two identical pictures of the lit lamp. Then the developed pictures are inserted into two opaque envelopes, A and B, and the envelopes are taken to different locations. This procedure should be conducted so that at this stage no human observer is aware of the generated color. Then nature has not yet decided for red or green; we have a macroscopically ambiguous state, with the pictures in the two envelopes quantum mechanically correlated: They are either both red or both green. If now a successful PK subject opens the envelope A, trying to enforce the appearance of the color red, this effort would be immediately afterwards observable as an increased probability for the color red in the envelope B. Again we would need a sufficient number of correlated picture pairs to have an efficient communications link.

For a practically more convenient study of this macroscopic quantum correlation effect, one could activate a binary random generator automatically many times and record the binary signals as clicks in the right or left channel, respectively, of a cassette tape recorder. Next one would copy the tape and then send one tape (system A) to a PK subject and keep the other tape (system B) in the laboratory. The subject would listen through stereo head-phones to the tape A trying to receive more clicks in, say, the right channel. Then a recounting of the clicks on tape B in the laboratory should find an excess of signals in the right channel.

Several similar experiments with slightly different forms of data storage and display have suggested the existence of the correlation effect,[13] in agreement with our model.

7. SUPERPOSITION OF TWO OBSERVATIONS

A. Binary event seen by two observers simultaneously

If two observers with parameters κ_1, ε_1 and κ_2, ε_2 look at the same binary event $Q = Q_1 = Q_2$ then these observers, according to (19a), act like one observer with the parameters

$$\kappa = \kappa_1 + \kappa_2, \qquad \varepsilon = \varepsilon_1 + \varepsilon_2 \tag{37}$$

and these are the parameters to be used in Equation (30) for the calculation of the total combined PK effect. Note that (for our nonegative κ values)

$$\frac{\varepsilon_2}{\kappa_2} < \frac{\varepsilon_1}{\kappa_1} \quad \text{implies} \quad \frac{\varepsilon_2}{\kappa_2} < \frac{\varepsilon}{\kappa} < \frac{\varepsilon_1}{\kappa_1} \tag{38}$$

so that the combined PK effect from the two observers cannot be stronger than the effect from the "better" PK subject alone.

Experimenters had initially assumed naively that the combined effort of two positive PK scorers should lead to an enhanced effect. But no such effect has been reported.

To understand our result intuitively, note that the PK effect occurs only in the process of reduction from the macroscopically ambiguous state into the collapsed state, and that each observer can apply his PK effort only to that fraction of the initial state that is not collapsed by the other observer.

B. Subsequent Observations of the same Binary Event

After one observer has, in our example, made completely certain whether the red or the green lamp is lit, we would expect a complete reduction, with a mixture given by (27), so that a subsequent observation of the lamps would change nothing.

But if the first observation were interrupted at some time t_0 so that the observer had only a subliminal impression of the color, then only a certain fraction ϑ of the initial state were reduced, leaving us with a mixture of the form [see (24) and (26) with $\vartheta = 1 - e^{-\kappa t_0}$]

$$\begin{aligned} \mu' = (1-\vartheta)\, \xi\rangle\langle\xi \oplus \vartheta \left(1 + \frac{\varepsilon_1}{\kappa_1} bb^*\right) aa^*\xi_1\rangle\langle\xi_1 \\ \oplus \vartheta \left(1 - \frac{\varepsilon_1}{\kappa_1} aa^*\right) bb^*\xi_2\rangle\langle\xi_2 \end{aligned} \tag{39}$$

Assuming subsequently a complete observation by the second observer, the final mixture becomes

$$\mu'(\infty) = (1 + \lambda bb^*)\, aa^*\xi_1\rangle\langle\xi_1 \oplus (1 - \lambda aa^*)\, bb^*\xi_2\rangle\langle\xi_2 \tag{40}$$

with

$$\lambda = \vartheta \frac{\varepsilon_1}{\kappa_1} + (1-\vartheta)\frac{\varepsilon_2}{\kappa_2} \tag{41}$$

An incomplete reduction, similar to (39) might also result if the human observer is half asleep or inattentive so that he forgets immediately what he has seen, or perhaps even if a cat or a cockroach has observed the lamps.

To test experimentally whether and to what extent a cat's observation might have reduced the initial state, let the cat's observation be followed by a complete human observation by an observer with known PK effect, $\varepsilon/\kappa > 0$.

Assuming that the cat reduces the fraction ϑ of the initial state, and disregarding for simplicity a possible cat PK effect, the final mixture becomes [(40) and (41) with $\varepsilon_1 = 0$, $\varepsilon_2/\kappa_2 = \varepsilon/\kappa$]

$$\begin{aligned} \mu'(\infty) = \left[1 + (1+\vartheta)\frac{\varepsilon}{\kappa} bb^*\right] aa^*\xi_1\rangle\langle\xi_1 \\ \oplus \left[1 - (1-\vartheta)\frac{\varepsilon}{\kappa} aa^*\right] bb^*\xi_2\rangle\langle\xi_2 \end{aligned} \tag{42}$$

Provided that we had an observer with sufficiently stable PK performance, we could measure his success rate with and without previous observation of the lamps by the cat. (The observer should not know whether or not there was a cat observing, so that he approaches both situations in the same mental state.)

Equation (42) gives for the success rates in the two situations

$$p(\text{without cat}) = \left[1 + \frac{\varepsilon}{\kappa} bb^*\right] aa^*$$
$$p(\text{with cat}) = [1 + (1 - \vartheta) bb^*] aa^* \qquad (43)$$

from which the value of ϑ can be derived.

C. Two Different Binary Observations

Consider two projections operators Q_1 and Q_2 corresponding to different binary macroscopic observations. Then we may assume[18] that these macroscopic operators Q_1 and Q_2 commute. With an initial state $\eta = \xi\rangle\langle\xi$ conventional quantum mechanics gives for the probabilities associated with the observations of one or both variables

$$P(Q_1 = 1) = \mathbf{Tr}(\eta Q_1), \qquad P(Q_2 = 1) = \mathbf{Tr}(\eta Q_2)$$
$$P(Q_1 = 1, Q_2 = 1) = \mathbf{Tr}(\eta Q_1 Q_2) \qquad (44)$$
$$\text{Same with } Q_1 \text{ or } Q_2 \text{ replaced by } \bar{Q}_1, \bar{Q}_2$$

If the expectation value for Q_2 is independent of the outcome of a previous Q_1 measurement, then

$$P(Q_1 = 1, Q_2 = 1) = P(Q_1 = 1)\, P(Q_2 = 1) \qquad (45)$$

or

$$\mathbf{Tr}(\eta Q_1 Q_2) = \mathbf{Tr}(\eta Q_1)\, \mathbf{Tr}(\eta Q_2)$$
$$\text{Same with } Q_1 \text{ or } Q_2 \text{ replaced by } \bar{Q}_1, \bar{Q}_2 \qquad (46)$$

Returning to our model, let us assume that first a complete observation of Q_1 (with κ_1, ε_1) is made and subsequently a complete observation of Q_2 (with κ_2, ε_2). By applying (27) twice we can easily calculate the final mixture and the probabilities for the four possible outcomes of the two observations. Let me list here explicitly only the resulting average value for the observable Q_2:

$$P(Q_2 = 1) = \left[1 + \frac{\varepsilon_1}{\kappa_1} \mathbf{Tr}(\eta \bar{Q}_1)\right]\left[1 + \frac{\varepsilon_2}{\kappa_2} \frac{\mathbf{Tr}(\eta Q_1 \bar{Q}_2)}{\mathbf{Tr}(\eta Q_1)}\right] \mathbf{Tr}(\eta Q_1 Q_2)$$
$$+ \left[1 - \frac{\varepsilon_1}{\kappa_1} \mathbf{Tr}(\eta Q_1)\right]\left[1 + \frac{\varepsilon_2}{\kappa_2} \frac{\mathbf{Tr}(\eta \bar{Q}_1 \bar{Q}_2)}{\mathbf{Tr}(\eta \bar{Q}_1)}\right] \mathbf{Tr}(\eta \bar{Q}_1 Q_2) \qquad (47)$$

In the special case that the observables Q_1 and Q_2 are independent in the sense of conventional quantum theory, (47) reduces with (46) to

$$P(Q_2 = 1) = \left[1 + \frac{\varepsilon_2}{\kappa_2} \mathbf{Tr}(\eta \bar{Q}_2)\right] \mathbf{Tr}(\eta Q_2) \tag{48}$$

i.e., in this case the outcome of the second observation is independent of any reduction or PK effect exerted by the first observer.

Let me mention in this context an actual experiment[19] performed in the following steps:

1. With the help of radioactive decays as sources of true randomness a six digit (decimal) random number is generated and recorded.
2. This number is observed carefully by the experimenter.
3. The number is fed as seednumber into a deterministic computer "randomness" program such as to produce a binary quasi random sequence.
4. The binary sequence is displayed to a PK subject as a sequence of red and green signals (or in some other way) while the subject tries to enforce the appearance of many "red" signals.

In part of the experiment the observation in step 2 was omitted. In this case the PK subject encounters a noncollapsed ensemble of many different possible color sequences corresponding to the different possible seednumbers so that the conditions for a PK effect were certainly given.

But the outcome of the experiment showed a PK effect also in the part where the experimenter had looked at the seednumbers. Thus there appeared to be no significant collapse, even though the experimenter had enough information to derive from the seed-number in principle (after some hours of pencil and paper calculation) the finally displayed binary sequence.

This result may help us to a better understanding of what constitutes a "conscious observation" that collapses the state vector. Note that the seednumbers did not convey meaningful information to the observer, or information he could remember (the large number of seednumbers used in the whole experiment were inspected in one sitting). It is true that the experimenter might have remembered some features of the seednumbers. For example, he might have counted the relative frequencies of even and odd seednumbers and that might have induced some partial collapse. But this count is independent of the frequencies of green and red signals in the binary sequence so that according to our previous calculation (48) this partial reduction does not affect the success of the PK effort.

7. CONCLUSION

Our main concern in this paper was the search for some self consistent formalism that might describe the reported psychokinetic effects. With experimentation in this field slow and tedious, and with the reported effects far outside the range of our everyday intuition, there is a need for theoretical models, no matter how tentative and preliminary, to help in the planning of systematic experiments.

Using the available frame of quantum theory to formulate such a first model seems economical: Many earlier attempts at changing quantum mechanics have shown that even "small" modifications of the formalism can lead to apparently unreasonable effects. And by postulating a particular "reduction mechanism" to accompany an observation, we are led to a logically self consistent model that can accomodate psychokinetic effects and makes quantitive predictions for future PK experiments.

On the more speculative side one might wonder whether the connection between quantum theory and psychokinesis is perhaps of a more profound nature. Could the singular role of the human subject as source of the PK effect be related to the controversial role of the observer in quantum theory, and does the reported PK effect on quantum jumps indicate some incompleteness in the current quantum formalism?

Taking this connection seriously, our model describes the reduction of a macroscopically ambiguous state in the process of observation as a "physically real" process. And the PK effect appears as a new tool for the physicist to distinguish between "collapsed" and "noncollapsed" states.

The model does not attempt to explain the nature of consciousness and its relationship to basic quantum theory. It treats the human observer and its interaction with the rest of the world in a purely phenomenological manner. Nevertheless, the model may be relevant with regard to very basic questions because it suggests that one aspect to consciousness, its action on the state vector collapse, can be approached experimentally.

In the presented, nonrelativistic formation of our model, we could uphold causality in a certain sense: Consider, for example, the case where a decision by a binary random generator is automatically recorded and one hour later inspected by an observer who exerts a psychokinetic effect. This might suggest that the later effort of the observer had affected the earlier random decision in a noncausal manner. But if we abandon the requirement of an absolute macroscopic reality and admit macroscopically ambiguous states, then at the time of observation the "physical reality" consists of the two options and the observer's efforts do not have to reach into the past in order to select one of the two offered possibilities.

In a relativistic generalization of the model, the collapse of the state vector might appear as a time symmetric "collapse and anticollapse"[20] and noncausality would be unavoidable. But whether such an interesting generalization is possible remains to be seen.

REFERENCES

1. H. Schmidt, *J. Appl. Physics* **41**, 462 (1970).
2. B. S. Dewitt and R. N. Graham, *Am. J. Phys.* **39**, 724 (1971).
3. B. d'Espagnat, *Conceptual Foundations of Quantum Mechanics* (W. A. Benjamin, Inc., Reading, MA, 1976).
4. J. von Neumann, *Mathematische Grundlagen der Quantenmechanik* (Springer, Berlin, 1932); English translation: *Mathematical Foundations of Quantum Mechanics* (Princeton U. Press, Princeton, 1955); F. London and E. Bauer, La Théorie de l'Observation en Méchanique Quantique (Hermann, Paris, 1939).
5. E. P. Wigner, "Remarks on the Mind Body Problem." in *The Scientist Speculates* (Basic Books, Inc., New York 1962), pp. 284–302.
6. L. E. Rhine and J. B. Rhine, *J. Parapsychology* **7**, 20 (1943).
7. L. E. Rhine, *Mind Over Matter* (Macmillan, N.Y., 1970).
8. J. Beloff and L. Evans, *J. Soc. Psychical Res.* **41**, 41 (1961).
9. R. Chauvin and J. Genthon, *Z. f. Parapsychologie und Grenzgebiete der Psychologie* **8**, 140 (1965).
10. H. Schmidt, *New Scientist and Science Journal* **24**, 757 (June 1971).
11. H. Schmidt, "Evidence for Direct Interaction between the Human Mind and External Quantum Processes." in *1977 Proceedings of the International Conference on Cybernetics and Society. IEEE*, Inc., New York.
12. B. Dunne, R. Jahn, and R. Nelson, "An REG Experiment with Large Data Base Capability." in *Research in Parapsychology*, (Scarecrow Press, Metuchen, N.J., 1981); R. G. Jahn, *Proc. IEEE*, Vol. **70**, No. 2, 136 (1982).
13. H. Schmidt, *J. Am. Soc. Psychical Res.* **70**, 267 (1967).
14. H. Schmidt, *Found. Phys.* **8**, 463 (1978).
15. E. H. Walker, "Foundations of Paraphysical and Parapsychological Phenomena." in *Quantum Physics and Parapsychology* (Parapsychology Foundation, Inc., New York, 1974).
16. R. D. Mattuck and E. H. Walker, "The Action of Consciousness on Matter, a Quantum Mechanical Theory of Psychokinesis." in *The Iceland Papers* (Essentia Research Associates, Amherst, WI, 1979), pp. 111–159.
17. O. Costa de Beauregard, *Psychoenergetics* **4**, 11 (1981).
18. G. Ludwig, *Die Grundlagen der Quantenmechanik* (Springer Verlag, Berlin, 1954).
19. H. Schmidt, *J. Parapsychology* **45**, 87 (1981).
20. O. Costa de Beauregard, *Found. Phys.* **6**, 539 (1976); O. Costa de Beauregard, *Found. Phys.* **10**, 514 (1980).