QUANTUM PARADOXES AND ARISTOTLE'S TWOFOLD INFORMATION CONCEPT

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The endeavor to solve the difficult problem of properly interpreting quantum mechanics which I am presenting in this essay today has a long personal history behind it—the history of a struggle to understand the relationship between mind and matter, first in the context of the theory of special relativity, then of the theory of probability and statistical mechanics, and finally of quantum mechanics, mainly in its relativistic expression. This long voyage might well be termed the story of a rational conversion to parapsychology. The central illumination of it consisted in the abrupt awareness that the cybernetic interpretation of *negentropy* as *information,* with the two symmetric procedures of gaining knowledge by decoding a message (that is, an ordered structure) *and* of emitting a message (that is, producing order) by means of one's *information*, was merely a technical restatement of what Aristotle had said long ago. Information is a two-faced medal: *cognitive awareness* on one side, *volitive awareness* on the other.

The point is, of course, that these two faces of conscious awareness—or, should we say also, with quite a few philosophers or biological thinkers—of *subconscious* awareness, are coupled to matter. *Information* is *negentropy; entropy* is the logarithm of a *probability;* and thus probability is neither objective nor subjective; it is *indissolubly objective and subjective, being the hinge around which mind and matter are interacting.*

Thus the intrinsic symmetry between the two facets of Aristotle's information—*cognition* and *volition,* in a broad sense—is tightly bound to corresponding symmetries in the real world. Gain in knowledge is coupled to a production of external entropy, that is also, as we shall see, coupled to the emission of retarded waves. Symmetrically, an ordering or volitive act is coupled to a destruction of external entropy, that is also coupled to an absorption of advanced waves. Such statements receive a very clear formulation in that highly specific blending of wave theory and of probability theory that quantum mechanics truly is. In this way the otherwise abstract association of causality with gain in knowledge on one side, of finality with volition on the other, finds itself dressed in lively attire. We can imagine with Leibniz (but *not* in deterministic style) the universe as containing myriads of (conscious or subconscious) monads exchanging *information* by means of quantized waves.

Having come to these views some time ago I was keeping them for myself, only letting the interested reader guess all about it by reading between the written lines, as we say in French. Then suddenly, the old Einstein-Podolsky-Rosen[1] (EPR) paradox—which is also the Einstein,[2] Schrödinger,[3] and Renninger[4] paradox—suddenly came to the center of the quantum speculations, mainly by the efforts of Bohm,[5] Bell,[6] Shimony,[7] d'Espagnat[8] and others. Resolving this paradox, together with one or two other ones, Schrödinger's cat paradox,[3] and Wigner's friend paradox,[9] became an international nightmare. At this point I decided I had something to say, and that I should dive right into the froggy pool. I have by now dived in it quite a few times, with the result that—thanks to the seemingly unsolvable EPR paradox—I was not "thrown out, as I would have been only five years ago" as a U.S. physicist put it. Another one said "If your intention was to show that all the well-known quantum paradoxes can be reduced to one, then certainly you have succeeded." According to a British physicist my thesis is "very logical," this perhaps implying (I really do not know) that it is schizophrenic. . . .

So let us proceed.

My starting point along this line of thought occurred in 1951 when I suddenly said to myself: If *you* truly believe in Minkowski's space-time—and *you* know you have to—then you *must* think of the relationship between mind and matter not at one universal or Newtonian instant, but *in space-time.* If, by the very necessity of relativistic covariance, matter is time extended as it is space extended, then, again by necessity, awareness in a broad sense must also be time extended.

Of course we know that our conscious awareness is tightly bound to the present. Bergson is very interesting when analyzing this fact. But then, and with Bergson, it is only natural to conceive consciousness as somewhat similar to the focalization of a *subconsciousness* that is time extended, towards the past of course, but *why not also towards the future?* Then it suddenly flashed in my mind that precognition, flashing into consciousness out of subconsciousness, but seemingly floating like a mirage above the horizon, without a solid connection to the general landscape, was not something irrational. Quite the contrary, it was something that should be expected according to the relativistic concept of space-time. Precognition, in this context, should look very much like the intuitions one occasionally gets when leisurely probing into a logically constructed treatise beyond the point reached by one's methodic and attentive study. This again is very Bergsonian, as for Bergson consciousness is *attention to life.*

That consciousness goes ahead through space-time, like one's methodic study goes ahead through the thickness of a written book, is of course commonplace in relativity theory. But one is entitled to ask *why* consciousness, or attention to life, is in fact bound to thus proceed. Boltzmann,[10] in his famous Treatise on Statistical Mechanics, here makes a striking guess. He argues that, according to Loschmidt's[11] and Zermelo's[12] well known paradoxes, there may well be in the universe just as many entropy decreasing as there are entropy increasing evolutions. Such a statement obviously implies that all physical evolutions are conceived as time extended, as in relativity theory. Let us denote these two classes by *F* and *C*, respectively. Boltzmann's guess is that both in the *F* and the *C* class the biological time of living entities is bound to go up, and not down the entropy curve. Therefore these two collections of living beings are exploring the time dimension in opposite directions. It is hard to conceive how they could exchange information.[13] Of course, as the physical arrows of increasing entropy and of retarded waves are one and the same, retarded waves are opposite to each other in the *F* and the *C* regions.

In its original form the Boltzmann apologue is hardly reconcilable with what we presently know of the universe, but the essence of the argument retains its flagrancy. We just have to think of two time-symmetric points with respect to the "initial" cusp of the evolutionary curve of an expanding universe, or else of two points near opposite ends of an arc of the curve of an oscillating universe.

Finally, as information theory tells us that knowledge must be gained at the expense of a preexisting negentropy, if we just postulate that, on the whole, knowing awareness prevails over willing awareness, we conclude[14] that the biological arrow is *de facto* (if perhaps not *de jure*) directed along rather than against the arrow of entropy increase and of wave retardation.

The next step of my rational pilgrimage through physics towards parapsychology was as follows.

All recent analyses of physical irreversibility by many physicists and/or philosophers of science,[15] including me, have shown that the irreversibility principle is of the nature of a boundary condition rather than of an elementary law of motion. It states, in the realm of either statistical mechanics or of the theory of waves, that *on the macroscopic level* one is *de facto* (if not *de jure*) allowed only to integrate the equations (the so-called "master equation," or the wave equation) by using an initial condition; it is forbidden to do so by using a final condition. Well known facts are expressed in this way. Nobody relies on shuffling cards to put a deck of cards in order. Or, by dipping a pipette into a glassful of mixed water and ink, one should not hope to have thus induced the ink to concentrate at the right point, so that the pipette could suck it. Such is the familiar situation prevailing inside a causalistic, or Carnot style, universe, whereas of course the reverse would occur in a finalistic, or anti-Carnot universe. To see how things would look in the paradoxical, anti-Carnot universe, one has just to run backwards any movie film. The result is, in almost every respect, fantastic.

To speak, as we have done, of a causalistic or of a finalistic universe is facile, but not quite right. As previously said, we should rather speak of the causalistic *versus* the finalistic *direction* along which our awareness is exploring space-time. To this we will come back at length.

Now I stress the logical connection existing between the two arrows of entropy increase and of wave retardation. For instance, if, between time instants t_1 and t_2, a physicist moves a piston in the wall of a vessel containing a gas in equilibrium, Maxwell's velocity distribution will be disturbed after time t_2, not before time t_1. Moreover, the disturbance is emitted as a retarded pressure wave, not absorbed as an advanced pressure wave.

It is in the realm of quantum mechanics—a theory where concepts of both probability and waves are inherent—that the connection is concisely expressible. A mere rewording of von Neumann's[16] celebrated proof of the irreversibility of the measurement process (implying his ensembles and his definition of entropy) shows that entropy increase and integration by retarded waves go hand in hand. In a more literary form the statement is as follows: While, as is well known, retarded waves are used in quantum mechanics for statistical prediction, symmetrically, as stated by Fock[17] and by Watanabe,[18] advanced waves should be used for statistical retrodiction. Thus, to say that, *macroscopically speaking*, blind statistical retrodiction is forbidden, or that advanced waves are nonexistent, is merely two different wordings for one and the same statement.

Let us now come back to information. Decoding a message is a *learning transition* where knowledge I is extracted from a preexisting negentropy, or macroscopic order N, according to the scheme

$$N \rightarrow I$$

where *de facto* (if not *de jure*)

$$N \geqslant I.$$

This is one face of Aristotle's information as rediscovered by cybernetics,[19] and an extremely trivial one. One buys a newspaper to get *information* from it. And one need not buy it for the advertisements, which go straight into the wastebasket. Retarded waves and entropy increasing evolutions are cascading everywhere, and most of them are not even used as information sources. This is a cybernetical rewording of Carnot's and Clausius' irreversibility principle.

The other face of Aristotle's information is far more recondite. It is in fact in private use by those few philosophers interested in will and in finality. It shows itself in the ordering or willing transition, where a preexisting conceptual scheme is used for producing macroscopic order, for instance, for sending a message, according to the scheme

$$I \rightarrow N$$

where, *de facto* (if not *de jure*)

$$I \geqslant N.$$

Why this second facet of Aristotle's information has fallen into general oblivion is a corollary of the *de facto* situation we are living in, where retarded waves outweigh by far advanced waves, or, in other words, where more probable complexions are coming out of less probable ones rather than the reverse. Looking at things from the subjectivistic side, we thus see that the willing transition $I \rightarrow N$ is as rare and hard to obtain as the learning transition $N \rightarrow I$ is common and easy. The social cost of the process is reflected in the high wages of workmanship or technical competence.

But perhaps the more subtle aspect of the reason for generally overlooking the second Aristotelian aspect of information is the following one. As we have said, increasing probabilities and causality go hand in hand, and so do causality and learning awareness. All this is the general trend around us. Trying to understand and analyze finality when looking from this side is simply hopeless, precisely because finality is as obvious to willing awareness as causality is to learning awareness. Practically, this means that if we are to uncover the rare and recondite instances of anti-Carnot processes *we must by necessity have recourse to an antipassive observational approach.*

It is the duty of fundamental research to explore the consequences of the *de jure* symmetries, existing in the mathematical formalism, which may well be hidden by large factlike asymmetries. A famous example of this is the experimental discovery of the positron by Anderson in 1932. The positron was mathematically present in the formalism of the Dirac equation, as an exact symmetric to the electron. It turned out that, though extremely rare (at least in this part of the universe we are living in), the positron really exists nevertheless. It is a member of a whole family of *antiparticles,* each mathematically implied by the corresponding particle.

Could it not be that advanced wave processes,[20] that is, probability decreasing processes,[21] which mathematically duplicate the trivial retarded waves and probability increasing processes, though *de facto* very rare, or at least not trivially producible, nevertheless exist around us? Putting the question is begging the answer. *Of course* they do exist; they must be at work in the very heart of biological phylogenesis and ontogenesis, not to speak of human activity. Of course, it is well known that those scientists more inclined towards operational reasoning than towards fundamental thinking have pointed out long ago, and are presently developing as an elaborate formalism, the *de facto* true idea that the order producing evolutions are growing like parasites on the universal order destroying evolution, from which they are sucking their information. This is an excellent remark—provided one does not stay at it, because, then the big question remains: "Whence does the initial information come, out of which the universal negentropy is cascading?" So let us not brush the dust under the rug, and face the fundamental question.

At this very point Quantum Mechanics has something significant to say.

In classical statistical mechanics, the occurrence of stochastic events was postulated without much discussion. In quantum mechanics, however, the mathematical formalism is so tight that it leaves no room for letting in the stochastic event without a very specific assumption. As emphasized by von Neumann[16] and by London and Bauer[22] one hardly sees any other possible issue than postulating that the stochastic event, or *quantal transition,* or *collapse of the wave function,* is induced by an act of consciousness on the observer's part. This is a very explicit statement concerning the subjective *and* objective character of the sort of probability that is involved.

This entails two important consequences that have not been stated up to now. The first one pertains to the coupling existing between different observers of the same quantal transition. If all of these observers are equally entitled to collapse the wave function, then all of them are bound together through the act of observation. *They must either cooperate or compete for producing the result.* Thus, even the learning transition is not so passive as it might have seemed at first; it may very well contain an active connotation. This is not surprising, since an *individual* stochastic event does not distinguish between retarded and advanced waves, and is entirely describable by means of (relativistically covariant) propagators.

The second consequence is tightly bound to the preceding one. It states that acts of will are *de jure* symmetrical to acts of cognizance, that is that, under appropriate circumstances, information as an organizing power should act as a sink of advanced waves, just as information as a gain of knowledge acts as a source of retarded waves.

It remains finally to be shown that psychokinesis and telepathy are implied in the above statements.

In the Schrödinger[3] cat paradox the cat is in a box and will be either killed or left alive according to whether the decay electron of a radionuclide goes, or does not go, through a Geiger counter. The amplifying device is of the usual sort, and the choice of the lethal weapon is left to the reader.

In ordinary statistical mechanics the cat is already either dead (D state) or alive (L state) when the experimental biologist opens the box. In quantum mechanics things are not so simple, if it is believed that it is the awareness of the observer, when opening the box, that collapses the wave function. Should we then say, according to the well known rules of quantum mechanics, that, after the atom has decayed, but before the observer takes a look, the cat is in a superposition, or interference, state, of the form $aD + bL$, with $|a|^2$ and $|b|^2$ denoting the respective probabilities that the electron does or does not trigger the counter? This certainly looks very much like a student's joke.

The point is, however, that the first informed observer—and the one that is primarily interested in the issue—is the cat himself. *He* must be the principal collapser of the wave function. One guesses, moreover, that a normal cat will be in favor of the *L* issue so that, using Aristotle's information in its recondite aspect, that is, calling from the past the appropriate advanced wave, he will incline the decay electron beside rather than through the Geiger counter. This is *blind statistical retrodiction,* and a *probability decreasing* process.

I need not say here that *precisely that* sort of experiment has been done many times by parapsychologists, not in the crude form of a death-or-life dilemma, but in the more sadistic form of a punishment-or-reward experiment. Dr. H. Schmidt[23] has built to this end a random outcome generator governed by radioactivity, and he has found, with quite a few other experimentalists, that not only cats, but also rats, or perhaps cockroaches, definitely favor rewards rather than punishments.

No better direct proof of the existence of anti-Carnot, or finality, processes could be given.

Having thus solved, by a theoretical explanation that is experimentally verified, the main core of Schrödinger's paradox, we immediately face another paradox. What if no cat is inside the box? Will not the radionuclide decay "according to the laws of probability"?

As we have decided from the outset that *every* stochastic event requires an act of consciousness in a broad sense, we are essentially left with two possibilities. The first one is that the wave function is collapsed by the first macroscopic observer taking cognizance of what has happened, maybe ten years later, and even if there is a clock registering at what time the nuclide has decayed. This is perhaps pushing one's faith in the existence of advanced waves too far.

The second way out of the problem is to postulate, with Leibnitz, Bergson, and quite a few other thinkers, the existence of very many monads, or rudimentary psyches, inside the universe. If no cat is inside the box, one or the other of these many "monads" will collapse the wave function, according to the usual rules of blind statistical prediction, because they are not vitally concerned with the issue.

There remains, however, the possibility that the human experimentalist's consciousness does contribute to collapsing the wave function. This brings into the problem some sort of telepathy between the cat and his tormentor. This is the very sort of problem that is at stake in the Einstein-Podolsky-Rosen paradox we are considering now.

The Einstein-Podolsky-Rosen[1] *paradox* was initially expressed in terms of nonrelativistic quantum mechanics; however, it is in the framework of relativistic quantum mechanics that it assumes its full significance.

Let us, for instance, consider a positronium atom decaying around time $t = 0$ near the point $x = y = z = 0$, and suppose it is in a spin-0 state. Then the decay electron and positron, which fly apart with opposite velocities, must have, according to the conservation law for angular momentum, opposite spins if their velocities are collinear. This statement makes no problem in classical statistical mechanics, where both spins are ordinary vectors, more precisely, *pseudo*vectors, but (as we shall see) it raises a serious problem in quantum mechanics.

One important point, however, needs to be made in the context of classical statistical mechanics. Suppose that observer E, observing the electron e, finds that its spin (which has been produced by a random event O occurring near $x = y = z = t = 0$) is represented by the vector $\mathbf{S}$. He is then *sure* that if another observer P, which may be operating far away from E, measures the spin of the decay positron p, he is bound to find that its value is $-\mathbf{S}$. This is because of the conservation law *and* the information E has pertaining to the initial event.

The question is: How is the inference drawn—or "how is the information telegraphed"—between E and P? Is it directly along the (four-dimensional) vector EP, which may be taken to be spacelike, and extremely large? This would violate Einstein's prohibition to telegraph outside the light cone.

The very mathematical formalism, however, shows that the inference is drawn not directly along EP, but along the two timelike vectors EO and OP forming a sort of Feynman zigzag. By this statement we are now violating Einstein's prohibition to telegraph into the past, but this prohibition is much less stringent than the former one, being of a factlike rather than lawlike character. It does

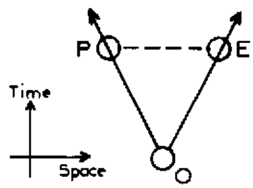

Figure 1. The Einstein-Podolsky-Rosen paradox.

not hold at the level of a single random outcome, where, quite the contrary, it is the *de jure* time symmetry of wave propagators that is enforced.

When leaving classical statistical-mechanics and entering quantum mechanics the sting of the EPR paradox becomes painful. Now, any two orthogonal components of the spin vector are no more simultaneously measurable, and both observers E and P are entitled to wait until the very last moment before deciding which component they will measure. In such circumstances the quantum measurement is said to contribute in producing the answer, so that, between observers E and P, we do not have only *telediction* as before, but also *teleaction*. The latter conclusion is the one that Einstein, Podolsky, and Rosen were ruling out as obviously absurd. But it is the one I must accept as the only one consistent with my overall philosophy. Moreover, *it is a conclusion that can be experimentally tested in the form of parapsychological experiments.*

Interest in the EPR paradox has now come to a climax due to the thinking of Bohm,[5] Bell,[6] and Shimony.[7] It has of course been known for a long time that the classical and the quantal stochastic formalisms, though similar in many respects, display some very specific differences that can in principle be tested. Bell has deduced the existence of such a testable difference in the case of spin measurements (or of polarization measurements for photons) in the EPR context. Quite a few recent experiments of this sort have been, or are being done,[23] the results of which are presently not consistent with each other. So we must wait and see.

However, in a Parapsychology Colloquium, the most attractive suggestion is to undertake the EPR type of experiments with, as agents E and P, not only impartial observers (as has been the case up to now), but also psychokinetic agents. Quite a few different combinations could then be tried.

Another famous quantal paradox is the paradox of Wigner's friend.[9] I will not delve into it here, because it borrows traits from both the preceding ones, and also because the sort of experimentation one could do with it is not too obvious. Now let us conclude.

It is of the very nature of waves to produce distant correlations in space-time. The scientific analysis of these correlations has already uncovered two major discoveries: Einstein's relativity theory in 1905, de Broglie's and Schrödinger's wave mechanics in 1925. I am submitting today that a third scientific revolution of comparable importance is implicit in the physics of waves.

It has been said that the relativity theory has lost the subject of the verb *to undulate*. If so, quantum mechanics, the legal heir of wave mechanics, has recovered it, and in a very unexpected form indeed. What is undulating through space-time is no longer the lost *ether*. It is the amplitude of a set of associated probabilities. Loosely speaking, it is *information*.

Now, according to Aristotle (the promoter of the concept) and to modern cyberneticists, *Information* is a two-faced medal: One side is gain in knowledge, the other is power of organization, that is, will. Thus, information is the very hinge around which mind and matter are interacting.

As the quantized waves are information waves, they are potentially propagating through space-time Aristotle's *de jure* symmetry between cognition and will, in the form of the *de jure* symmetry between retarded and advanced waves, that is also, as we have seen, of entropy increasing and entropy decreasing processes, of causality and of finality.

I need not say that if this is the true state of affairs, relativistic quantum mechanics is a conceptual scheme where phenomena such as psychokinesis or telepathy, far from being irrational, should, on the contrary, be expected as *very rational*. My thesis is that they are postulated by the very symmetries of the mathematical formalism, and should be predicted for reasons completely akin to those that had led Einstein to enunciate the principle of special relativity, de Broglie to produce the concept of matter waves, and Dirac to (almost) predict the positron.

Was it not Schrödinger who exposed witchcraft in the quantum paradoxes?

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DISCUSSION

PUTHOFF: Just as backup for what Dr. de Beauregard said, I might mention that when we've been using very sensitive instrumentation, one of the first things we've observed—a number of times—is that when a person just observes the system, that alone, without any apparent effort on his part, will produce perturbations in the output.

BEAUREGARD: This is very interesting. True, there are many more things in physics than one thought there would be.

FEINBERG: I would like to make two comments on Schrödinger's cat, one of which is relevant to the reduction of the wave packet. One has, at the outset, a superposition of two wave functions where this is a wave function caused by the cat being dead, and that the wave function of the cat being alive. *A* and *B* are coefficients. The sum of the squares is 1.

The reduction of the wave packet specifically refers to the transition from the first situation, which is called a pure state in quantum mechanics, to a situation where you have either the cat alive, or the cat dead, with a probability *A* squared, or the cat alive, with a probability *B* squared. This second situation is called a mixture and is the way one would describe in classical physics the situation before the box is opened.

Now, in cases like the one described in the Einstein-Podolsky-Rosen experiment of the decaying atom, there is a physical difference between having a superposition and having such a mixture, in the sense that you can prescribe very simple experiments, which Einstein and the others did prescribe, which give different results in one or the other circumstance.

Experiments which give different results, however, have one very simple characteristic. They all involve the measurement of quantities which have an interference between this wave function and that wave function. In the Einstein-Podolsky-Rosen case, where the two wave functions referred to different spin projections, it's very easy to find such a measurable quantity. Particularly, you can measure the spin along a different axis.

In the case of Schrödinger's cat, I defy anybody to find a measurable quantity which involves an interference between a dead cat and a live cat. The dead cat and the live cat are thermodynamically different states. It's an irreversible transition from one to the other. Therefore, any quantity which one can imagine measuring, which does not involve a reversal of entropy, will automatically give the same result for the pure state as for this particular mixture. Therefore, it seems to me that the example of Schrödinger's cat does not really bring out the question of the reduction of a wave packet in a clear way. I therefore think it's better to use other examples.

You referred at one point to the possibility that the cat, which prefers being alive to being dead—especially if it's at the end of eight of its lives—would automatically choose to realize this probability rather than that probability, perhaps by deflecting the radioactive particle, the decay electron.

Now, I want to remark that there are circumstances in which living things have the opportunity to influence radioactive decay rather directly. I am referring here not to Dr. Schmidt's experiments, but rather to experiments which have been done by biologists involving speeding radioactive materials to living creatures. These radioactive materials, at least in some experiments, kill the creatures fairly rapidly. The period depends on the material and the creature and so on.

I would think that if it's possible for these living beings to influence the rate of decay of radioactive materials in a very significant way, that is, say, to change the absolute halflife of a radioactive source from one year to three years, that they would choose to do it under those circumstances, thereby increasing their life span beyond what would happen with the radioactive decay. I believe that measurements have been made of the radioactive decay rate of materials that are bound in biological systems in this way. Yet, I've never heard of anybody recording a difference between the decay rate that is detected that way and the decay rate of the isolated atoms. But I would say that it is possible for living things to influence radioactive decay, only the mode of influence must be a rather different one than a direct change of the decay rate or something along those lines.

BEAUREGARD: What you are saying is that the cat *is* collapsing the state vector, like any other macroscopic device, a photographic plate for instance. But this is what I am saying also, when I expose the Schrödinger assumption as an untenable one.

Concerning your second point, perhaps the living things first have to learn how to do this. They may have an opportunity to learn in the experiments of the parapsychologists. Naturally, such an opportunity will be lacking when it is a life or death dilemma.

FEINBERG: Maybe we should try to build up such learning, first in small amounts, then larger amounts, until they do change radioactive decay.

BEAUREGARD: The irreversibility of this procedure is customarily accepted in statistical mechanics where it is used in blind statistical prediction. But precisely what is at stake is that perhaps we must consider conditional probability rather than blind statistical prediction to be effective. I am thinking here of Professor Helmut Schmidt's work where a parameter B is introduced, thus using Bayes's *a priori* coefficients. Conditional probability would be a way of saying that a certain amount of advanced waves enters into the process of precognizing.

Let me put things quite bluntly. If we had pure advanced waves, we would not have collapse, but *anti*collapse, in the sense that the measuring procedure would act as a sink of advanced waves rather than as a source of retarded waves. Also, we would have blind statistical retrodiction instead of the usual blind statistical prediction.

However, in a realistic context, one should not have so much faith in parapsychology; that is, there will be some contribution from both retarded and advanced waves, so that Bayes's *extrinsic* coefficients will creep into both prediction and retrodiction. This is exactly what I mean when saying that will (in a broad sense) will tend to "collapse the state vector this way or the other." I mean loading the intrinsic probabilities by Bayes's extrinsic ones.

FEINBERG: That may be, but it is not the same as saying the wave packet is reduced by the living being. The reduction of the wave packet is specifically the change from the top line to the bottom line. If that is not what happens, the reduction of the wave packet does not occur, but rather some other process.

BEAUREGARD: What I mean is that the wave function jumps into one discrete new state with a statistical frequency different from the one that is calculated by standard predictive means. That is, that Bayes's conditional probabilities come into the *predictive* calculation, or else that there is an advanced wave contribution.

SCHMIDT: Dr. Beauregard mentioned that if radioactive decay is introduced into the living environment of an organism, certain changes may be expected in the instigating agent but more so in the subject. These changes should be compared with other experiments in parapsychology. We know, for example, that for an efficient performance you have to make the situation very exciting. If possible individual feedback must be obtained for each event, where it is made clear that you are there to experience the event. It is not enough that you just sit there and let the event happen, but there must be an active involvement, and the outcome must be of importance. I would not, as a negative instance, simply ask a person, "Please try to speed up this decay; we will count it for half an hour." I would not expect a PK effect there. But if you present the task as a challenge, "There is a red lamp which goes on, but only if you are smart enough to find the switch to make it go on," then it works. And if you offer rewards, then it works even better. We don't quite understand this experiment. We would be much happier if we could get PK effects in a routine situation but so far we have not succeeded. This may be a fact we have to live with.

FEINBERG: The experimenter can sense that the insides of the animal are being eaten away by the radioactive decay. The animal itself may not know exactly what's happening to it, but it certainly has some feeling that it is not functioning as well as it might.

My comments are more along the line of Dr. de Beauregard's points that perhaps other beings than human are able to affect the superposition. If it can be affected by what we call lower animals, like cats or cockroaches, then at least to me, the question of psychology is hard to solve.

SCHMIDT: Yes, but motivation is of major importance. If there is a motivation in the animal, a response may be produced. Perhaps it will not occur otherwise. Let us assume there is a cat in a cold room, with a lamp which goes on sometimes. If the cat sits there and waits long enough for the heat lamp to come on, it will. So the cat is motivated to wait. At least we have a motivation similar to that provided in PK tests with humans.

PIRON: Perhaps Dr. Costa de Beauregard realizes that the paradox he pointed out is more or less the same as the Einstein paradox. Nevertheless, there is a change, and that is our problem. In the Einstein paradox, it is possible to measure the difference between the two states, i.e., the pure state and the mixture. On the other hand, I do not know what the difference is for the example of the cat.

Explicitly, everyone thinks that the state of the cat after exposure had to be the mixture, not the pure state where it is *both* dead or alive. But quantum theory—or, at least, the old quantum theory—predicts that the latter is the correct one. There are many other difficulties with this kind of theory.

The difficulty is that one must describe not only the mixture of the states "dead" or "alive," but also the mixture of all the positions of the cat in the box. If the same reasoning is applied to all positions, this state cannot be built in the conventional or old framework of quantum theory. This produces the paradox. People speak of a paradox because they see no way to find the state which seems to be the real state of the system.

Quantum theory has progressed, however, and it is now perfectly possible to write an equation in the new version of the theory which will describe whether the cat is dead or not, in the usual classical sense.

This is not the significant point in the Einstein-Podolsky experiment. However, the paradox arises in the Einstein-Podolsky experiment where a large amount of time was allowed. After this time the particles were very far apart, and one cannot understand why a measurement made on one part of the system will affect the other part. That is the paradox.

If a measurement like this one is made at the beginning when the two particles are close together, no one can claim that this measurement affects only one part and not the other part of the system. Paradox arises only when the particle separation is very wide.

It is difficult for quantum theory to explain this change from the local initial state to the real final state, where the two parts of the system are widely separated.

In the case of the cat's paradox the difficulty is of two orders. The first difficulty is to derive a formalism which describes the state at each time. The second difficulty is to give an equation of motion.

As far as our problem is concerned, the first difficulty is completely solved. We already have the formalism according to which one can explain how the correlation disappears.

The description of the state of such a system at each time was found and published about three years ago. The formalism for the equation of motion is much more complicated.

FEINBERG: Well, I'm not sure to what extent we're agreeing or disagreeing. What I said originally about the cat is that there is no conceivable physical difference between these two circumstances. Therefore, one doesn't know whether one actually finds this situation or the other, since any measurement will be equally in agreement with the two of them.

In the case of the Einstein-Podolsky-Rosen correlations, it seems to me that what one finds is the following. In this case it shouldn't be, dead or alive; it should be, alpha and beta. One finds that if you do the measurement ensemble the wave function of the combined system, when the particles have gone far apart, is described by the first linear combination, not by the second. Of course, there is still a somewhat open question. Certain physicists have advanced a slightly alternative non-quantum-mechanical theory, which makes different predictions than quantum mechanics. As far as I know, the measurements performed so far all agree with quantum mechanics. Some of them are not necessarily in disagreement with other theories, but there has never been a measurement done to my knowledge which disagrees with the prediction of quantum mechanics for a situation like this.

Therefore it seems to me that one is not talking here about an experimental problem, but rather about how comfortable one is with a particular theoretical description. That was certainly the problem of Einstein, Podolsky, and Rosen. They simply did not like the logical consequences that this description led them to. Other physicists have had no particular objections to it. But in no case, to my knowledge, is there a disagreement between an experiment that has been done, and the prediction of this particular state.

PIRON: Yes, it is true that all experiments on this subject are very difficult. However, the point is that if you make the experiments, when the two particles are close together, there are no paradoxes. A greater distance is required to justify the paradox. Einstein and Podolsky would not claim that this initial state is paradoxical. But when the particles separate very far, you never in practice take such paradoxical state to explain the system.

FEINBERG: Yes, you do. If you measure the *X* component of spin on this one, far away, and measure the *X* component of spin on that one far away, you get the opposite answer. If you measure the *Y* component of one and the *Y* component of the other, you also get an equal and opposite answer. That is what the top line predicts. It is not what the mixture predicts. The mixture predicts that there would be no correlation between the *Y* spins, i.e., there could not be a simultaneous correlation between one set of spins and the other set of spins. There is in that case a physical difference.

PIRON: I agree that there is a physical difference. The paradox arose because the usual rule of quantum theory would predict—paradoxically—another correlation. This can be attributed to a nonlocal effect in the two apparatuses.

FEINBERG: The measurements have been done. But I do not understand why distance should constitute a variation in these effects. If you let the electron pass through a second apparatus, the item that is the superposition is the product wave function of the electron in the first apparatus. Then you still have to look for interferences between the different states of the apparatus.

PIRON: One has that difficulty in principle. However, the reason that there are no difficulties in the experimental facts is that the facts say there is no difference. Given the distances used in the experiment to obtain the superposition, no difference is found. On the other hand, the theory predicts a little difference.

BEAUREGARD: It would certainly be very interesting to carry out experiments with a great distance. It may be that the coherence length of the wave train is significant, and that the correlation becomes weaker as the particles separate very far. My main point, however, is that this correlation proceeds in space-time not directly along a spacelike vector, but rather along two timelike vectors. It thereby affects this specific event after the situation has been generated, that is backwards in time.