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THE SCHRODINGER'S PARADOX
AND THE TRANSFORMATION OF QUANTUM SYSTEMS[*]

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Abstract : The Schrödinger's paradox is analysed, as an illustration of certain weaknesses of the Copenhagen's interpretation of quantum mechanics and of the limits of the quantum-mechanical description of phenomena. A realistic approach of the paradox indicates the necessity of a theory that would permit not only the calculation of probabilities, but also the description of physical processes, as taking place in space and time. It is argued that the paradox exists only as far as we accept the Copenhagen's interpretation.

Résumé : On analyse le paradoxe de Schrödinger, en tant qu'illustration de certaines faiblesses de l'interprétation de la mécanique quantique par l'école de Copenhague et des limites de la description quantique des phénomènes. Une approche réaliste du paradoxe montre la nécessité d'une théorie qui permettrait non seulement le calcul de probabilités, mais encore la description de processus

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Feature No

Kuyatt *et al.* (1965)

Zapesochnyi and Shpenik (1966)

6^3P_1 $\lambda = 2537$ Å

7^3S_1 5461 Å

6^3D 3650 Å

8^1S_0 4916 Å

Fano and Cooper (1965)

physiques, se déroulant dans l'espace et le temps. La thèse soutenue est que le paradoxe n'existe que si on accepte l'interprétation de l'école de Copenhague.

1. The paradox

The apparently humoristic paradox of Schrödinger(24), continues to raise debates among physicists(1, 14, 15, 17, 27, 28). This is explained by the fact that the "cat paradox" raises questions concerning the conceptual foundations of quantum mechanics : the superposition principle, the "reduction of wave packet", the rôle of the measuring instrument, and the relations between micro-and macro-reality.

Let us begin by quoting E. Schrödinger : "A cat is placed in a steel chamber, together with the following hellish contraption (which must be protected against direct interference with the cat) : In a Geiger counter there is a tiny amount of radioactive substance, so tiny that may be within an hour one of the atoms decays, but equally probably none of them decays. If one decays then the counter triggers, and via a relay activates a little hammer which breaks a container of cyanide. If one has left the entire system for an hour, then one would say that the cat is still living if no atom has decayed. The first decay would have poisoned it. The Ψ function of the entire system would express this, by containing equal parts of the living and dead cat.

"The typical feature in these cases is that an indeterminacy is transfered from the atomic to the crude macroscopic level, which then can be decided by direct observation (Quoted form(15)).

We propose now a modification, such that nothing essentially changes, while making the situation more suitable for our analysis : The quantity of radioactive substance is such, that surely one a-particle is emitted during the experimentation time Δt. The particle is emitted either to the right or to the left, and this with equal probabilities. In the first case the event is amplified, the instrument activated and the cat killed. In the second case nothing happens.

According to the "bon sens" (which in our case is conformable with reality) the cat is either alive or dead at the moment of observation : the observer has nothing to do with its fate. But it is well known that according the Copenhagen interpretation of quantum mechanics (CI) the cat and the apparatus form -after the interaction- a unique system in superposition, evolving deterministically. So it is the observation that "reduces the wave packet", and effectively saves or kills the cat.

So the CI affirms, or implicitely presupposes :

1. That the radioactive substance, plus the instrument, the cyanide and the cat, form one unique system.
2. That this "great system" can be described in quantum-mechanical terms.
3. That the great system is (after the interaction) in superposition : $\Psi = C_+\Psi_+ + C_-\Psi_-$, with $|C_+|^2 = |C_-|^2 = \frac{1}{2}$ and evolves in a deterministic way, according the Schrödinger time-dependent equation.
4. That this state is "reduced" by the act of observation. So, it is an external intervention that changes the state of the system (and kills or saves the cat).

2. A more precise formulation of the problem

Let us accept (for the moment) that the radioactive atom is described by a state vector $\Psi = \frac{1}{\sqrt{2}}(\Psi_r + \Psi_\ell)$ and the apparatus by a state vector Φ_0. (This state vector represents the apparatus plus the cat).

Before the interaction, the whole system is represented as the factorized state vector

$$\Psi = \Phi_0(x_1,x_2,\ldots)\Psi \qquad (1)$$

this factorisation being possible, since there is no interaction between the two systems.

During the very short interaction time interval τ, the two systems constitute a unique system in superposition :

$$\Phi_0(x_1,x_2\ldots)\left(\frac{1}{\sqrt{2}}(\Psi_r+\Psi_\ell)\right) \xrightarrow{\text{interaction}} \frac{1}{\sqrt{2}}\left(\Phi(d_1,d_2\ldots)\Psi'_r + \Phi(a_1,a_2\ldots)\Psi'_\ell\right)$$

According the CI, this system is a pure state evolving in a deterministic way. *As von Neumann affirms, no "reduction" is possible during this time*(19). So we are obliged to arrive to the paradoxical conclusion, that the cat is now in a superposition of states : "cat alive" *and* "cat dead" and this with equal statistical weight. It is the observation that transformes this state into a mixture :

when the observer "looks" into the system, the "wave packet" is reduced, and one of the two possible states is realised. Our state is now :

$$\Phi(a_1,a_2\ldots)\Psi'_\ell \quad \textit{or} \quad \Phi(d_1,d_2\ldots)\Psi'_r \qquad (3)$$

It is well known that the formalism of quantum mechanics does not describe this "reduction". The intervention of the observer, on the other hand, does not help -as we shall see- in the clarification of the situation.

The above state of affairs and its conventional interpretation, raises a number of fundamental questions (discussed already by many authors).

1. Does the quantum mechanical description concern one individual system, or an ensemble of identical and identically prepared systems ? In the first case, which is the meaning of (2) and (3) ?
2. Which is in particular the physical meaning of the assertion that the radioactive atom is before the desintegration in a superposition of states ?
3. *Is it legitimate to assert that the macroscopic instrument is described by a state vector ? In other words, is it legitimate to extent the quantum-mechanical formalism to macroscopic, and a fortiori to biological systems ?*
4. What does the factorisation of Φ and Ψ mean, if our response to question 3 is negative ?
5. Which is the physical meaning of the "superposition" provoked by the interaction of the two systems ? *The superposition concerns an individual system, or a statistical ensemble of identical systems ?* And is it a realised state, or is it a measure of the potentialities of the statistical ensemble under definite external conditions ?
6. What does the term "reduction of the wave packet" mean ? Does it describe a physical process, or is it a formal concept that masks the real process of transformation of quantum systems ? Our analysis bears essentially on these questions.

3. The statistical meaning of the state vector

The statistical interpretation of quantum mechanics (Max Born, 1926) is generally accepted, but it is not respected in practice, and especially by CI. In fact, the assertion : cat alive and cat dead, presupposes a non-statistical conception for the state vector. It means in practice, that the state vector describes an individual system S. (This is evidently true in the trivial case, where the state space is one-dimensional. But this case is a special one)[*].

It is well known, that it makes sense to speak of statistics and probabilities, for statistical ensembles only. In the case of quantum mechanics, these ensembles are formed of "identical and identically prepared systems". So let us accept that the superposition makes sense for a statistical ensemble : that it expresses the fact that such an ensemble, described as a pure state $\Psi = \sum_n C_n \Psi_n$ (4) has the possibility to be transformed, under the action of an apparatus (or some other physical interaction) into a mixture of states $\{\Psi_n\}$, with definite probabilities $p_n = |C_n|^2$. We can then affirm that (4) expresses simply the *possibilities* of formation, under suitable conditions, of a mixture of proper states $\{\Psi_n\}$, and not a real superposition of states preexisting the act of measurement.

We have in that case a qualitative transformation :

$$\Psi \xrightarrow{\text{interaction}} \{\Psi_1,\Psi_2,\ldots\Psi_n\}$$

with $p_n = |\langle\Psi_n|\Psi\rangle|^2$.

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[*] One may argue that CI deals with ensembles, not single systems. Formally this is true. But the case of the paradox under discussion, as well as many other conceptions of the orthodox school, show that this is not the case in practice. Exemples : 1) The concept of wave packet, as is usually understood (the wave packet is, e.g., half reflected by a mirror). 2) The interpretation of Heisenberg inequalities as concerning individual systems. (The frequency of a single photon, e.g., presents then a dispersion $\nu \pm \Delta\nu$. As a consequence the individual photon has no precise energy). 3) The superposition principle, more generaly, is understood as something concerning the single system. (So each individual system is considered as described by $\Psi = \sum_n C_n \Psi_n$). 4) The expression "Ψ describes a microsystem" appears currently in the litterature, etc. The existence, on the other hand, of a statistical interpretation (Einstein and others), shows that CI is not a coherent statistical interpretation of quantum mechanics.

The equation $\Psi = \sum_n C_n \Psi_n$ is usually considered as expressing an *identity*. It gives the impression that the states preexist, that they are in superposition, and that the rôle of the apparatus is to project or to analyse something already existing. According the point of view developped here, this equation is an expression of the potentialities of the system under given external conditions. So the superposition principle does not concern real states, but the set of possibilities of the initial state. (The Hilbert subspace H in which Ψ belongs, is not a space of realised states ; it is a *space of potentialities*). The superposition principle, as usually understood, mask the physical process of *transformation* of S.

In the case of the cat experiment, the CI leads to the non-realistic conclusion of superposition and *interference* between cat alive and cat dead (Cf for ex.(3)). In fact we have a qualitative transformation of S, the amplification of the micro-event, and the splitting of the initial statistical ensemble into two sub-sets : *cat alive, cat dead*.

We propose in consequence the following modification of the experiment : Instead of one system S + A, we construct a great number N of apparatus A, and suppose that we catch N poor cats. This experiment with N "great systems", allows us to affirm *a priori*, that within the time interval Δt, $\frac{N}{2}$ cats will be killed and $\frac{N}{L}$ cats will rest alive. This certainty is an expression of the statistical character of quantum-mechanical description. A coherent statistical interpretation of quantum mechanics, makes it possible to avoid the statements about "cat alive" *and* "cat dead". It permits to affirm that the final state is a statistical mixture of two states : Ψ_a and Ψ_d in equal proportions. But the question : *How a "pure state" is transformed "spontaneously", or under the action of an apparatus into a mixture*, remains unanswered. But before facing it, we should analyse the relation between the microphysical and the macrophysical parts of the experiment.

4. Microphysical and macrophysical systems

As already noted, the usual interpretation of the paradox presupposes that the quantum mechanical formalism can be applied to macroscopic systems also.

It is J.Von Neumann who attempted treating this question mathematically(19). In fact it is practically impossible to carry out such a programme, because of the complexity of the systems, which makes the necessary calculations impossible(25). This programme is also theoretically untenable : The difference between S and A is not only a question of complexity or scale ; there is also a question of *qualitative difference* and of a theoretical impossibility to reduce higher level of organisation to lower ones. (This "reductionism", makes part of the mechanistic conception which caracterizes the Copenhagen's school).

According the CI, we need an observer who will induce the "reduction of the wave packet". One is then inclined to think that the existence of the observer introduces a subjective element in the whole situation. So some authors tried to eliminate this element. Einstein replaced the instrument by a film recording the radioactive decay in a completely objective way(9). L.L.van Zandt proposes on the other hand to replace the cat by a less complex apparatus, in order to avoid any possible question of basic differences between animate and inanimate matter(28).

Suppose -in order to objectivize the phenomenon- that we replaced the observer by a photographic apparatus. The radioactive atom S and the instrument A,which form after the interaction one "great system" S+A, will continue to form a pure state according to (2) : the cat will continue to rest half alive and half dead, in the eternity.

But in a real experiment the cat will be dead an instant after the desintegration of the atom if the particle is emitted on the right, and the photographic plate will register its death in a completely objective way. We can arrange to register also the moment of its death. (The signal that activates the apparatus is transmitted in a finite interval of time). The fate of the cat is in fact decided at the moment of the radioactive decay. It is this "spontaneous" transformation of a quantum system that determines the final "state" of A, and not the hypothetical "reduction" of a macroscopic (and partially biological) system.

Quantum mechanics cannot describe the decay of S, as being a physical process realized in a finite interval of time. It cannot foresee the moment of desintegration (it can make statistical previsions only). But is is obvious (and contrary to the CI) that from the moment of the decay, S and A cannot form a unique system : the proper state Ψ_r or Ψ'_ℓ is already realized (so the microsystem ceases to be in a "superposition" of states) and the *irreversible* process of amplification and registration starts. Thus, any possibility of interference between S and A is excluded.

So, we can distinguish the following phases in the experiment,

1. Independence of S and A and factorisation of the "state vector".
2. Decay, creation of a proper state of S.
3. Amplification of the signal (if the state Ψ_r is realised) and creation of the "state" : *cat dead.*

In the more general case of *measurement*, the final state is determined by the interaction of the quantum system with the microscopic part of the instrument. We can in fact devide (at least conceptually) the instrument, into two parts : the microscopic part m and the macroscopic M, and imagine a *boundary* F, between the two. The boundary is not to be considered as a "cut" -in the formal sense of the word- but as an open domain, where the microscopic event begins transforming into a macroscopic phenomenon. The result of the measurement is thus determined by the interaction S+m : the whole process is *irreversible* and is realized in a finite time interval.

In the case of the Schrödinger paradox, the final result depends only on the transformation of S : The instrument has nothing to do with the direction of emission of the particle. In the general case, however, the instrument can play an active rôle during the measurement (create the proper states $\{\Psi_i\}$ by transforming the initial ensemble).

The distinction between microscopic and macroscopic is considered essential by some authors. Thus Taketani thinks that "a cut" can be located in the region where the microscopic event is transformed into a macroscopic phenomenon(26). S. Sakata considers on the other hand that one essential mistake of von Neumann was that he applied quantum mechanics to the apparatus, though it is a macroscopic system(23). There are on the contrary, authors, who take a rather sceptical attitude concerning the question of boundary. Thus Jauch says (with the voice of Sagredo) that nobody knowns the exact position of this boundary, and that with this notion we introduce into the description of nature a *dichotomy* which destroys the unity of science. Jauch considers that the question is a pseudoproblem, and that should be no boundary(16).

The reserves of Jauch appear reasonable. But if -as already indicated- we consider the boundary not as a cut, but as the domain where the microscopic ends and the amplification begins, then we can avoid to destroy the interplay of continuity-discontinuity, as well as the unity of micro-and- macro-reality. This means that we can, in principle, distinguish between S, m and M, as well as between m+S and M. But this *separability* is not formally opposed to the *non-separability* (interconnection, mutual determination) of S, m and M. At the same time it is evident that S and A do not differ only in scale. Their physical properties, as well as their functional rôles, are different.

The assumption that S+A+O constitutes a unique (quantum) system, disregards the fact that during the measurement we have to do with a macroscopic *irreversible* process, generated by a micro-event. The irreversibility and the temporal hysterisis exclude any superposition and interference beyond the boundary. So we cannot speak of quantum process and of state vector beyond F. The quantum formalism cannot describe neither the amplification, nor any other macroscopic process generated by the microscopic signal.

5. Interaction and transformation of quantum systems

We must discuss now, more concretely, the question : *How the transformation of a microsystem (the so called reduction of the state vector) occurs in nature, or under the influence of a macroscopic apparatus ?*

Let us at first examine the case of "spontaneous" radioactive decay. The state of the atom in our experiment is represented by

$$\Psi = \frac{1}{\sqrt{2}}(\Psi_r + \Psi_\ell) \qquad (5)$$

According to the CI this is a pure state, a real superposition of proper states Ψ_r and Ψ_ℓ. According to V. Fock, (5) expresses the potentialities, or the potential possibilities of the system (12). As long as there is no external perturbation, this state vector evolves continuously. The question then arises : *How this pure state is transformed "spontaneously" into a mixture ?*

In reality, we write (5) *a posteriori* : on the basis of the *empirical fact* that the radioactive substance desintegrates via two channels, and this with equal probabilities. Equation (5) says *nothing more* : it can describe, neither the real state of S, nor the processes underlying its transformation.

Or, we can understant, at least qualitatively, this transformation if we take into consideration the fact that S is in a continuous and random interaction with its environment. Its transformation should then be considered as the result of the interplay of its internal variables (interactions of the A type), with the environment (interactions of the B type)(18,2). We should in fact suppose, that the state of S possesses an internal *fine structure* of dynamical character, and that the "reduction" is nothing else than the transformation of the state, provoked by the interplay of A and B interactions[x].

The continuous "deterministic" evolution :

$$i\hbar \frac{\partial \Psi}{\partial t} = H\Psi \qquad (6)$$

presupposes an ideal situation, where the fluctuation B type interactions are so weak, that they cannot lead to any transformation of S, and thus they can be neglected.

The state vector, as Einstein puts it, yields the probability that the particle is emitted in a certain direction, but it does not imply any assertion concerning the time instant of the desintegration. Einstein finally affirms, that this theoretical description cannot be taken as complete(9). We should add that this description says nothing about the irreversible processes underlying the phenomenon.

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[x] The variations of B type interactions do not represent a kind of hidden variables in the usual sense of the term. They represent the variations of the couplings of physical systems, via ordinary and known interactions (electromagnetic, strong and weak). As a result of these random variations, the hamiltonian of S has no an absolutely constant value, but is subject to random variations. This assertion further means that an ideal isolation of S is impossible. The isolated system is an abstraction never realized in nature, but nevertheless useful for the description of cases where variations of B interactions are negligible.

Let us now return to our experiment. The factorised "state" vector :

$$\Psi = \Phi_0(x_1,x_2\ldots)\Psi$$

expresses the fact that the interactions between S and A are negligible : it expresses the mutual independence of the two systems, and nothing more.

The "reduction" of (5), that is to say, the radioactive decay, is an internal problem of S, related to the interplay of A and B type interactions. It has nothing to do with the existence of the macrosystem A. (As it is well known, this *qualitative* transformation is not described by the actual linear formalism of quantum mechanics).

Now, the direction of emission of the a particle, determines the sort of the cat (the creation of the "eigenstate" of Φ_a or Φ_d, if we insist to apply quantum mechanics to this macroscopic-biological system). If we use an initial ensemble of N identical systems, this is now a mixture : $\frac{N}{2}$ cats alive and $\frac{N}{2}$ cats dead. The mixture is generated by the action of S on A, and is realised before any observation. It is in one to one correspondence with the mixture Ψ_r and Ψ_ℓ generated by the "spontaneous" transformation of S.

In the more general case of a measuring process, the eigenstates $\{\Psi_n\}$ are really produced out of Ψ, by the action of the apparatus (interactions of the C type). The effect of measurement in that case is to convert a pure state into a mixture. The assertion of the CI : no pure state can be transformed into a mixture, is a formal statement of identity, which presupposes that we do not take into account the qualitative changes produced by the action of an external system on the quantum system.

E. Wigner speaks of a sort of dualism in the evolution of the state vector(27). In the frame of the usual interpretation this dualism is inevitable. But this inconsistency disappears and the unity of physical processes is restored, as soon as we consider the "spontaneous" decay as the result of the interplay of A and B type interactions, and the "reduction" provoked by the apparatus, as a result of the interplay of A and C type interactions. In the ideal case where B = 0, the system will evolve in a "deterministic way", according to (6).

One can find in the litterature two contradictory points of view :

1. The eigenstates are created by the apparatus, which transforms a pure state into a mixture (Bohr, Fock, etc.).
2. A pure state cannot evolve into a mixture. In order to obtain a mixture as a result of an interaction, the initial state should have been already a mixture.

We think that the first statement is the correct one, but that it must be analysed concretely.

There are cases where the proper state Ψ_n *preexist*. The interaction S+A does not lead to any modification of the quantum system. It simply registers the existing eigenvalue. It is the state of the apparatus that is changed, in one to one correspondence with Ψ_n. So we have :

$$\Psi_n\Phi_0 \xrightarrow{\text{interaction}} \Psi_n\Phi_n \qquad (7)$$

This *irreversible* phenomenon corresponts to an ensemble forming a pure state in the narrow sense (one dimensional state space, or "charp" state, as Wigner says it). There is no statistical element here, no creation of proper states, and (consequently) no "reduction" of state vector. The only dispressions are the statistical dispressions, expressed by the Heisenberg's inequalities.

The case of separation of a mixture into its components (pure states), is analogous.

Let us take now the more general case of a superposition : $\Psi = \sum_n C_n \Psi_n$ with $\sum_n |C_n|^2 = 1$. The total system S+A is initialy described by the factorized state vector.

$$\Psi = \Phi_0\left(\sum_n C_n \Psi_n\right) \qquad (8)$$

The act of measurement consists in the coupling, during a short time interval τ, of S with A. The initial system (8) becomes then, in accordance with the evolution of S+A :

$$\Phi_0\left(\sum_n C_n \Psi_n\right) \xrightarrow{\text{interaction}} \sum_n C_n\left(\Phi_n,\Psi_n\right) \qquad (9)$$

The orthodox interpretation affirms that (9) represents *a pure state*, which will evolve again in a deterministic way. No reduction is possible, and the observer is the *deus ex machina* invented in order to transform this state into a mixture. The "conscious ego" introduces a subjective element in the process of measurement. This "solution" leads to a solipsistic philosophy, rejected by the majority of physicists(14).

But why should the observer provoke the "reduction" of this state ? According the CI, we must consider him as part of the whole system : we have now a system S+A+O, which would evolve again deterministically, and so on. The same argument is valid in the case that we shall use another apparatus, A', to lead to the reduction. In the limit, the whole universe must be considered as a unique system, where no real transformation is possible, and where nothing will really occur(10). (For a criticism of von Neumann's "radically subjectivistic" philosophy, see also(7)).

The formalism of quantum mechanics does not describe the process of transformation of a pure state into a mixture. But this is the essential question. The assumption that the initial state is already a superposition of real states is physically untenable. To say, on the other hand, that it is already a mixture is contrary to the formalism and transforms the act of measurement into nothingness.

The continuist language (wave function, wave packet, reduction, etc.), constitutes the back-ground of this interpretation. Considering the quantum system as wave packet and its transformation as a "projection" or "reduction", leads to contradictions and to physically untenable situations*.

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* There is no unanimity concerning the physical significance of the wave-particle duality. Waves and particles are, according to Bohr, equally essential and exclusive aspects of reality(4). Heisenberg affirms that it is impossible to have something which is at the same time a wave and a particle, and that the apparent duality expresses a limitation of language(13). Fock, on the contrary, thinks that the microparticles are waves and particles, in the same time(12). Popper writes about *propensities*, and accepts no dualism of particles and waves(21). Finally Bopp(5), as well as many others, affirms that quantum mechanics deals with particles, and that the waves are relating to statistical ensembles of particles.

The "reduction" is considered not as a process taking place in a finite time interval, but as an instantaneous passage from one state to another. For some authors a rigorous reduction of the wave packet occurs under certain conditions(14). For others this reduction never happens, the necessary time being infinite((14), see also J.S. Bell, CERN preprint, TH 1923). According to Stapp the "collapse" of the wave packet is incompatible with the superposition principle(25). And it is well known that the wave packet has no permanent existence, as it spreads over the whole space.

So, the fiction of the wave packet and the *non* statistical interpretation of the state vector, lead to the most paradoxical situations. Consider, e.g., a particle incident upon a semitransparent mirror. The particle is *either* reflected, *or* transmitted. But the wave packet is divided, partly transmitted and partly reflected by the mirror(1).

A statistical and corpuscular interpretation on the contrary gives a reasonable account of these phenomena. No "reduction" of the quantum system is taking place, but a qualitative transformation, as a consequence of its interaction with the apparatus. The "division" of the "wave packet" is nothing more than an expression of the statistical distribution of the results of a great number of collisions, etc.

We have thus :

$$\Psi \xrightarrow{\text{measure}} \{\Psi_n\}$$

This is an *irreversible* qualitative transformation of the initial system, generated by the action of the measuring instrument. The irreversibility is a fundamental, and yet an unknown aspect of the measuring process. Quantum mechanics describes stationnary phenomena, but not irreversible transitions, as taking place in space and time. The Schrödinger's equation is incapable to describe this evolution of the quantum system(11).

The projection postulate is a formal expression of the phenomenon, incapable to explain the real physical processes underlying the transformations of quantum systems. Quantum transitions are not instantaneous. They are very rapid but continuous transitions from one state to another, and their nature is to be understood (1). (See also : Bunge-Kalnay, *Fundamenta Scientiae*, 11, 1976).

The transformation of the quantum systems under the action of the apparatus, has also its thermodynamic counterpart.

As P.C.W. Davies explains, the initial conditions of the apparatus is thermodynamically metastable. So, a small perturbation results in a transition towards a thermodynamically stable state. In our case the transition is unduced by the interaction with the observed system. The metastability is an indispensable prerequisite for the transition and the amplification of the quantum signal. The apparatus proceeds in a fairly rapid way to the new equilibrium state, which depends on the initial state of S(7,8). Every measurement leads to a definite position of the pointer. The statistical dispersion of the positions concerns the case where the initial ensemble forms a superposition of states (no sharp initial state).

The spectrum of $\{\Psi_n\}$ in the case of a "spontaneous" transformation, may be considered as resulting from the interactions of the system with its environment. The distribution of probabilities is however determined by the nature of S. In the case of a measurement, the spectrum is determined by the nature of S, and the conditions of the experiment. The same ensemble of systems and the same apparatus can give different spectra, according the conditions of the experiment.

But as already noted, this case is not a general one, and the assertion that the system is *not* in an eigenstate before the measurement is not a general validity. We can in fact distinguish three types of measurement :

1. A pure state (in the narrow sense : one proper state already realised) is simply recorded by the apparatus. The rôle of the instrument is passive. No proper state is created. (The eigenvalue is in a state of random fluctuation, because of the interplay of A+B interactions, but this is another aspect of the problem related to Heisenberg's inequalities).
2. A mixture is analysed into its components (pure states). No creation of proper states occurs.
3. A pure state (superposition of states) is transformed into a mixture : $\Psi \xrightarrow{\text{measure}} \{\Psi_n\}$. The states Ψ_n are generated by the interaction of A and S. *This is the only case of creation of eigenstates.*

The expression $\Psi = \sum_n C_n \Psi_n$ is a formal expression of identity. It is a tautology. But the state before measurement is *not* identical with that after the interaction of S and A. The above expression is a measure of probabilities, that is to say, a measure of the potentialities of the system under given conditions. The probabilities $p_n = |C_n|^2 = |<\Psi_n|\Psi>|^2$ are the probabilities for new states, not pre-existing the act of measurement.

So, if the quantum system S is not in one of the eigenstates of the state space of the measuring instrument, the interactions A+C may result in the qualitative transformation of S, and the creation of the proper state.

The generally multidimensional state space to which Ψ belongs, is not the space of the actual states before measurement, but that of the potentially possible ones. So -as already stated- we cannot consider as identical Ψ and $\{\Psi_n\}$, but as two physically different ensembles : one pure state and one mixture, the second being generated via an irreversible qualitative transformation. It is the interplay of A and C type interactions, which transforms Ψ into $\{\Psi_n\}$, thus interrupting its continuous "deterministic" evolution.

According to H. Putnam, the axiomatisation of von Neumann takes the measurement as primitive, and postulates that each measurement results in a "reduction of the wave packet". But measurements, says Putnam, are only a certain subclass of physical interactions. So we have to demand that this subclass should be specified with sufficient precision, and without reference to any element of human consciousness$^{(22)}$. In the special case of Schrödinger's paradox, the instrument plays no rôle in the creation of eigenstates, which result from the game of A and B type interactions.

The preceeding analysis proves lack of knowledge, as fas as the physical significance of the superposition principle is concerned. E. Wigner puts the question whether this principle will have to be abandoned. But the real problem should be to find out the physical processes involved in the transformation of quantum systems, that is to say, the processes underlying the transformation $\Psi \to \{\Psi_n\}$.

6. Superposition, Mixtures and Interferences

It is well known that if a state Ψ is a superposition of states Ψ_+ and Ψ_-, there exists the possibility of interference

between Ψ_+ and Ψ_- :

$$|\Psi|^2 = |C_+\Psi_+|^2 + |C_-\Psi_-|^2 + 2\mathrm{Re}\, C_+^{\star} C_- . \Psi_+ . \Psi_- \qquad (10)$$

In the case of the paradox, the CI postulates, as noted, the existence of interferences between the states *cat alive* and *cat dead*. According to this interpretation the mixture :

$$\Phi(a_1, a_2 \dots)\Psi'_\ell \qquad \text{and} \qquad \Phi(d_1, d_2 \dots)\Psi'_r$$

is realised only after the actual observation, which destroys the interference phenomena.

But interferences are realised only with coherent states. If the states are incoherent or orthogonal, no interference occurs. What kind of coherence is then possible, between a microscopic system, a macroscopic apparatus and a living organism ? These states (if we accept their existence) must be incoherent. No interference between living and dead cat is therefore possible. As Hepp puts it, the states of living and dead cat with 10^8 disintegrated neurons should be rightfully described by disjoint states. (According the point of view developed here, no quantum description is possible in that case).

This impossibility is further demonstrated by the fact, that at the moment of interaction between S and A, the system S is no longer represented by (5) : *the desintegration has destroyed the "superposition"*. We have thus a state Ψ_ℓ which provokes no effects, or a state Ψ_r, which generates a macroscopic and irreversible phenomenon.

The question is more delicate in the general case of measurement. In that case it is possible for the equation (10) to correspond to observable effects, as in the famous two slit experiment. But these interferences constitute a special class, distinct from that of the type of cat experiment, and their physical interpretation remains always unclear.

In the case of pure state transformed into mixture by the measuring apparatus, coherences are possible in the microscopic part of the "great system" (in S+m). These coherences must be conserved, according the CI, as long as no observer looks into the system. According to the point of view developed here, the coherent states (if they exist) *can split into disjoint states*, as a result of the interplay of A, B and C interactions.

Even if we accept that macroscopic bodies can be described in quantum mechanical terms, it is impossible to produce interferences in the two parts of the large system. As L.L. Van Zandt shows it, if so much as one particle, electron, nucleon, photon, etc., fails to overlap in the two branches of superimposed wave function, no local operator can exhibit interference effect. The same author thinks that in order to have such effects, the size of the total system cannot exceed the position acertainty of the constituent particles(28). This is an argument in favor of the point of view developed here : that if interference phenomena occur, they must concern only the microscopic part of the instrument, that is to say, S+m*.

In the case of creation of proper states during the measurement, we have to do with a non-linear transformation, not described by the (linear) laws of quantum mechanics. This is not a reason to imagine non realistic models in order to cover our ignorance. As Einstein puts it, the true laws of physics cannot be linear. Linear laws, writes, fulfill the superposition principle for their solutions, but contain no assertions concerning the interaction of elementary bodies. The true laws cannot be linear, nor can be derived from such(9). The paradox of Schrödinger reduces -according a certain point of view- to absurdity the superposition principle. One could affirm that it puts, more generally, the question of the physical meaning of the foundations of quantum mechanics.

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*There is an analogy here, with the exclusion principle. So we think useful to quote W. Pauli on this subject : "From a superficial consideration of the exclusion principle, it might be thought that a sort of action -at-a-distance is being postulated, as a result of which, even two widely separated particles are aware of one another ("sign a contract"). However this is not so, because the exclusion principle is only valid as long as the wave packet of the two particles overlap. If the wave packets do not overlap, then everywhere in the space we have $U_{n_1}(x^{(1)}, S_1^{(1)}).U_{n_2}(x^{(2)}, S_2^{(2)}) \equiv 0$(20). This clear position is contrary to non-separability of the CI interpretation, which implicitely presupposes the existence of instantaneous interactions.

7. Concluding remarks

The formalism of quantum mechanics describes an enormous variety of phenomena. Its validity is in no way questioned. This formalism makes it possible to calculate probabilities and probabilities of transition between quantum states. The quantum mechanics is on the contrary unable to describe physical processes that produce qualitative changes, as phenomena occuring in finite intervals of time.

The cat paradox is an illustration of the limits of the conceptual foundations of this theory, and of the fragility of Copenhagen's interpretation. It makes clear that we ignore the physical meaning of the superposition principle, of the "reduction of the wave packet", of the phenomena of coherence and interference, of the time evolution and of the transformation of quantum systems.

Schrödinger's paradox illustrates the need for a quantum mechanics of physical processes, and not only of probabilities and probabilities of transition.

Finally, there is no cat paradox. There is a lack of knowledge, and an interpretation which transformes this lack of knowledge into mystery.

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