QUANTUM INFORMATION, IRREVERSIBILITY AND STATE COLLAPSE
IN SOME MICROSCOPIC MODELS OF MEASUREMENT

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Abstract

The quantum measurement problem considered for measuring system (MS) model which consist of measured state S (particle), detector D and information processing device O. For spin chains and other O models the state evolution for MS observables measurements studied. It’s shown that specific O states structure forbids the measurement of MS interference terms which discriminate pure and mixed S states. It results in the reduction MS Hilbert space to O representation in which MS evolution is irreversible, which in operational formalism corresponds to S state collapse. In radiation decoherence O model Glauber restrictions on QED field observables results in analogous irreversible MS + field evolution. The results interpretation in Quantum Information framework and Rovelli’s Relational Quantum Mechanics discussed.

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1 Introduction

The fundamental problem of irreversibility and in particular the state vector collapse in Quantum Mechanics (QM) is still open despite the multitude of the proposed models and theories (for the review see [1]). This paper analyses some microscopic dynamical models of quantum measurements which attempt to describe the evolution of the measuring system (MS) from the first QM principles. In this models MS includes the measured state (particle) S, detector D amplifying S signal, environment E and observer O which process and store information. Under observer we mean information gaining and utilizing system (IGUS) of arbitrary structure [2]. It can be both human brain and some automatic device processing the information, but in both cases it’s the system with many internal degrees of freedom (DF) which permit to memorize the large amount of information. In general the information processing or perception in case of human brain is the physical objects evolution which on microscopic level supposedly obeys to QM laws [3]. For example, the information bit transfer in standard computer corresponds to the electrons motion inside the semiconductor chips. Such process can induce the back-reaction on the information gained in the measurement and must be accounted in the general measurement theory. In this paper we’ll use the brain-computer analogy without discussing its reliability and philosophical implications [4]. We’ll ignore here quantum computer options regarding only standard solid-state dissipative computers.

The possible role of observer in the wave-function collapse was discussed for long time [5], but now it attracts the significant attention again due to the the progress of quantum information studies [6]. The formal description of standard QM and its generalization for different observers in terms of Information Theory was developed by Rovelli [6]. We can’t describe here this formalism called Relational QM at length citing only the features essential for quantum measurements. In particular its definition of quantum information via correlations between S and O states will be used throughout the paper.

Standard Copenhagen QM interpretation divide our physical world into microscopic objects which obeys to QM laws and macroscopic objects, also observers which are strictly classical. This artificial partition was much criticized, first of all because it’s not clear where to put this quantum/classical border. Moreover there are strong experimental evidences that at the dynamical level no such border exists and QM successfully describes large, complicated systems including biological one. Following this conclusions Relational QM concedes (Hypothesis 1 of Rovelli paper) that QM description is applicable both for microscopic states and macroscopic objects including observer O which Dirack state vector $|O⟩$ can be defined relative to some other observer $O'$, which is also another quantum object. The evolution of any complex system C described by Schrodinger equation of some (may be very complicated) form and for any C including MS the superposition principle hold true at any time. Let’s consider in this ansatz $O'$ description of the measurement by O which starts at $t = t_0$ of binary observable $\hat{Q}$ on $|s⟩ = a_1|s_1⟩ + a_2|s_2⟩$, where $|s_{1,2}⟩$ are $Q$ eigenstates. It follows from the linearity of Schrodinger equation that for $t > t_1$ when $O$ finished to measure S state the state of MS system relative to $O'$
observer is
\[ \Psi_{MS} = a_1|s_1\rangle|D_1\rangle|O_1\rangle + a_2|s_2\rangle|D_2\rangle|O_2\rangle \]  
(1)

Here \(|O_1\rangle\) is \(O\) state vector after finishing the measurement of particular \(S\) state \(|s\rangle = |s_1\rangle\) (and correspondingly for \(s_2, O_2\)). After S-D-O interaction (measurement) finished and \(O\) internal state changed, it means \(O\) memorizes the quantum information about \(Q\) value for \(S\) state. For example \(|O_{1,2}\rangle\) can correspond to some excitations of \(O\) internal collective DF like phonons, etc., which conserves this information. For the simplicity in the following we’ll omit detector \(D\) in measurement system \(MS\) assuming that \(S\) directly interacts with \(O\). It’s reasonable for simple models, because if to neglect decoherence the only \(D\) effect is the amplification of \(S\) signal to make it conceivable for \(O\). In our formalism we’ll use \(C\) general relative pure states \(|C_i^o\rangle\) which in principle can differ from Dirac vectors. Here the lower index marks \(C\) parameters and upper one - observers (for \(O, O'\) they are 0, 1), for example \(\Psi_{MS} = |MS^1\rangle\).

Relational QM formalism by itself can’t resolve the state collapse enigma but give us some additional insight from the comparison of \(O, O'\) observers reports on \(S\) measurement result. In this approach at time \(t > t_1\) for observer \(O'\) MS is in the pure state \(\Psi_{MS}\) of (1). Yet we know from the experience that at the same time \(t\) \(O\) perceives the final MS state as the mixed state \(\rho_m\), which means the state collapse. Considering this paradox we must notice that MS measurement by \(O\) formally includes the measurement of \(O\) own internal DF or selfmeasurement \([7]\). In relation with it Ashtekar proposed phenomenologically that for observer \(O\) some of its own internal DF \(Q_U\) can be principally unobservable \([8]\) and ref. therein). If so then for observer \(O\) the result of selfmeasurement described taking the trace over \(Q_U\) and due to it \(O\) subjective state \(|O^0\rangle\) always percepted as mixed one. If this state entangled with \(S\) state after \(S\) measurement then the complete MS state is also looks mixed for \(O\), but not for \(O'\). To investigate this promising idea it would be interesting to look for this unobservable DFs in some measurement models.

The selfmeasurement problem often regarded as the implication of more general algebraic problem of selfreference \([1]\). Following this approach Breuer has shown that the phenomenological selfmeasurement restrictions for classical and quantum measurements are analogous \([7]\). Yet at least in quantum case they are introduced ad hoc and don’t obtained from Schrodinger linear MS evolution. In fact Breuer formalism needs additional QM collapse postulate in a weaker ‘subjective’ form. In our approach we’ll follow different route assuming that MS evolution in selfmeasurement is also linear and obeys to Schrodinger equation of some form. Then we’ll try to find the restrictions and unobservable DFs in some microscopic IGUS measurement models. In chap. 2 it will be shown that Heisenberg commutation relations for \(O\) operators and \(O\) particular atomic structure restricts the information acquisition and results in collapse-like evolution. Decoherence effects can be important also in IGUS selfmeasurement models \([8]\). To check it in chap.3 we’ll consider the particular mechanism of MS radiation decoherence which applied for the information memorization in the realistic IGUS models. In chap. 4 we’ll discuss the physical and phylosophical implications of described models results.

To relate our models with Measurement Theory we’ll introduce strict measure-
ments defined as follows: for observable \( Q \) defined on \( h_s \) - \( S \) subspace of MS Hilbert space, exists \( Q_o \) on \( h_o \) - \( O \) subspace, for which \( \bar{Q} = \bar{Q}_o \). The same definition can be used for detector \( D \), operator \( Q_D \) and its subspace \( h_D \). The difference operator \( \Delta Q = Q - Q_o \) defines measurement uncertainty and estimate of information available for \( O \) on \( Q \) value. If \( \Delta Q = 0 \) this is exact measurement transferring maximal information on \( Q \) value for \( S \) state. For the case when only detector \( D \) considered in the model the strict measurement in fact describes any realistic experiment [1]. This is close analog of the measurement of first kind, but if observer also included in the model some new features appears, as will be shown below.

The formal selfmeasurement definitions have some distinctions (compare [3] and [7]), but for our models they are inessential. As the example of selfmeasurement let’s consider some automata \( O \) which consist of ensemble of independent binary pointers \( |G_{ij}⟩, i = 1, 2, J = 1, N \). Each pointer can interact with external state \( S \) or other pointer and ‘measure’ their states analogously to eq. (1). If some \( O \) program control pointers \( G_j, G_k \) interaction sequence then \( O \) performs selfmeasurement [3].

In our models we’ll suppose that MS always can be described completely (including \( E \) if necessary) by some state vector \( |MS⟩ \) relative to \( O' \). MS can be closed system, like atom in the box or open pure system surrounded by electromagnetic vacuum or \( E \) of other kind. Throughout this paper the operational definition of collapse used: if any (self)measurement performed by \( O \) can’t indicate the difference between mixed and pure MS state then this state perceived by \( O \) as mixed one. The results of measurements in this approach estimated and compared by \( \bar{Q}_O \) value of any true observable \( Q_O \). This definition isn’t complete by itself and can’t account the ’problem of event’ directly [4], but for models study it’s quite useful.

### 2 Quantum Information and IGUS Model

Till now there are only few attempts to construct the observer microscopic models which can make discussion more fact-like [3]. Here we consider the simple microscopic IGUS model of information processing and memorization which reveals some of its important features. IGUS selfmeasurement restrictions must be defined by IGUS physical structure, in particular its atomic structure. Due to it even macroscopic observer can store only finite amount of information and this IGUS finiteness will be shown to have important consequences for quantum information acquisition. Moreover it’s reasonable to demand that the (self)measurement process shouldn’t destroy IGUS structure or obstacle to its proper functioning and conserve previously stored information. It’s reasonable to express this conditions via structure conserving operator \( \hat{R} = \prod \hat{P}_j \), where \( \hat{P}_j \) are some projection operators describing IGUS structure. All the physically consistent IGUS states must be \( P_j \) eigenstates and this conditions should be fulfilled also during and after the measurement. For example if IGUS has the atomic crystal lattice, then projector \( \hat{P}_r \) permits only limited range of distances between neighbor atoms \( |r_{i,i+1}| < a_0 \) in IGUS state vector.

We consider first the toy-model based on Coleman-Hepp (CH) model which used often for QM paradoxes discussion [10]. CH model considers fermion \( S^0 \) spin z-
projection measurement via interaction with $N$ spin-half atoms $A_i$ linear chain - 1-dimensional crystal detector $D$. $A_i$ atoms are regularly localized at the distance $r_0$ by the effective potential $U_i(x_i)$. $S^0$ initial state $\psi^0_0 = \varphi(x, t_0)(a_1|u_0) + a_2|d_0)$ where $u, d$ are up, down spin states and $\varphi(x, t_0)$ is localized $S^0$ wave packet spreading along D spin chain. For the comparison the measurement of corresponding mixed state $\rho^0_m$ with weights $|a_1, 2|^2$ will be regarded. $S^0 - D$ interaction Hamiltonian is:

$$H_I = (1 - \sigma_z^0) \sum_{i=1}^N V(x_i) \sigma_x^i$$  \hspace{1cm} (2)

where $V$ is $S^0 - A_i$ interaction potential. For suitable model parameters and for D initial polarized state $\psi^D_0 = \prod |u_i\rangle$ one obtains that if $S^0$ initial spin state is $|u_0\rangle$ this D state conserved after $S^0$ passed over the chain, but for initial state $|d_0\rangle$ D state transformed into $\psi^D_x = \prod |d_i\rangle$. Thus for finite $N$ at $t > t_1$ for $S^0 - D$ final state

$$\psi_f(t) = \psi_1(t) + \psi_2(t) = \varphi(x, t)(a_1|u_0)\psi^D_x + a_2(-i)^N|d_0\rangle\psi^D_x \quad (3)$$

we get macroscopically different values of D pointer which described by the polarization operator : $\mu_z = \frac{1}{N} \sum \sigma_z^i$ acting in $hD$ subspace. It gives estimate $\bar{\mu}_z = \bar{\sigma}_z^0$ and $\bar{\Delta}_Q = 0$, so this is strict exact measurement. Despite, it doesn’t mean $S^0$ state collapse because $S^0 - D$ interference terms (IT) operator:

$$B = \sigma_x^0 B_I = \sigma_x^0 \prod_{i=1}^N \sigma_y^i$$  \hspace{1cm} (4)

describing spin-flips of all $A_i$ and $S^0$ spins. In principle $B$ also can be measured by observer $O$ and discriminate $S^0 - D$ mixed and pure states. Its expectation value $\bar{B} = .5(a_1^*a_2 + a_1a_2^*)$ for $S^0 - D$ final state $\psi_f$ differs from $\bar{B} = 0$ for $S^0$ mixed state $\bar{\rho}_m^{0, [1]}$. For the convenience we exclude from consideration $a_1, a_2$ values such that $\bar{B} = 0$, which doesn’t influence on our final results. Note that $S^0$ IT can be measured separately, but only before $S^0 - D$ interaction starts, after it only their joint IT operator have sense. $\mu_z, B$ don’t commute and can’t be measured simultaneously:

$$[\mu_z, B] = \frac{i}{N} \sum_{i=1}^N \sigma_z^i \prod_{j \neq i}^N \sigma_y^j$$  \hspace{1cm} (5)

It’s easy to propose how to measure collective (additive) operator $\mu_z$, but also $B$ values can be destructively measured decomposing $D$ into atoms and sending $A_i$ one by one and also $S^0$ into Stern-Gerlach magnet. Then measuring $A_i$ amount in each channel and their correlations by some other detector $D'$ one obtains information on $B$ value from it. Note that $B$ measurement isn’t strict for $D$ subspace, but is strict for $D'$, the fact which will be used below. Standard QM don’t regard any special features of destructive measurements assuming that any hermitian operator is observable and can be measured by one way or another.

Of course CH model only crudely imitates the evolution of real detectors which are the collective solid states characterized by the strong atoms selfinteraction. In
CH model it’s accounted only by effective potential $U_i$ and don’t depend on $A_i$ state. If one wish to consider closely the effects of atoms selfinteraction on the interference terms then for CH model it can be simulated by neighbor spins interaction adding to $H_f$ Heisenberg Hamiltonian describing ferromagnetism: $H_f = J (\vec{\sigma}_i \cdot \vec{\sigma}_{i+1})$, where $J$ is spins interaction potential called also exchange integral. Note that our D initial state $\psi_D^0$ is $H_f$ eigenstate and the excitations of this states by $S^0$ for large $N$ are described by spin waves - magnons [12]. This changes our picture only in this sense that now the operators describing D state - $\mu_z, B$ must be changed to some time dependent operators , but commutation relations still are the same and all our conclusions will be true for them. The more realistic imitation of real detectors seems the electron excitations and the lattice excitations - phonons which dynamics reminds the magnons one very closely [12]. Note that due to selfinteraction the studied D state will be largely perturbed if one tries to decompose D into atoms for IT operator $B$ measurement [13].

From analogous considerations some authors assumed that for collective selfinteracting systems D IT operators are unobservable and so can explain the collapse [10]. We don’t regard this hypothesis as well founded and at least it needs consistent proof of such restrictions existence, analogously to described IGUS restrictions.

Extending this ideas to construct the observer or IGUS models one should take into account that observer performs the selfmeasurement of its own state and so obeys to additional $R$ restrictions.. For example let’s consider that the input signal induces inside solid state IGUS the electron loop current state $|\psi_J\rangle$, which stipulate signal perception. The electron currents in brain or processor in general are very complicated, but for the simple model of binary state measurement we assume that one of this states - $|d_0\rangle$ excite in the conducting loop the current and other one - $|u_0\rangle$ not. Then neglecting fermion statistics the current operator have additive form $\vec{J}^p = \sum e \vec{v}_i$, where $\vec{v}_i$ is the electron velocity operator, which for this binary signal has only eigenvalues 0 and $\vec{v}$. So in first approximation the current operator structure is analogous to CH model $\mu_z$ polarization and we can study distinction between the pure and mixed states for it to understand some effects for current states.

For this purpose let’s consider ensemble of $N_c$ CH spin chains as our IGUS $O$ performing $S^0$ spin measurement and start with $N_c = 1$. In CH model the information about $S^0$ spin acquired and memorized by $O$ in the form of observable $\mu_z$ eigenstates superposition of (4). Normally IGUS consists of acquisition (perception) channel AC which interact with S , transfer and amplify its signal and memory cells MC which interact with AC and memorize information about S. In CH model we formally can regard first $N - 1$ atoms as our AC and $A_N$ as single MC for which $\vec{\sigma}^N_z = \sigma^0_z$. But for simplicity we’ll consider the spin chain as AC and MC simultaneously, so MC subspace for $N_c = 1$ is $h_O$. Memorization by MC can be only strict measurement, alike $\mu_z$ memorization in $h_O$. It’s impossible for $O$ to memorize $B$ value because it isn’t operator on $h_O$ only.

The real difference of $S^0 - O$ measurement by single chain from $S^0 - D$ measurement described above is that for given $O$ structure it is principally impossible to perform $B$ selfmeasurement by $O$. To demonstrate it let’s compare $S^0 - D$ interac-
The interaction finished the observer \( O' \) with \( S^0 - O \) interaction observed by same \( O' \). In first case after the interaction finished the observer \( O \) had the choice to percept and memorize \( \mu_z \) or to decompose \( D \) into atoms and measure \( B \) and to verify that the state is pure or mixed. In the second case when \( O \) finished to interact with \( S^0 \) pure state and memorized \( \mu_z \) for \( O' \) the system \( S^0 - O \) final state is also \( |(S^0 - O)^0)\rangle = \psi_f \) of (3). We settled preliminarily that \( O \) state should obey to \( R \) restriction and in particular \( P_r \) which means that \( O \) spin chain can’t be decomposed into atoms. Yet if \( B \) measurement as we assumed can be only destructive for \( O \) and destroy its chain structure then after it \( O \) simply stops to function and can’t memorize \( \mu_z \) or \( B \) information. So we conclude that for properly functioning observer \( O \) operator \( B \), or more exactly \( B_I \) is principally unobservable. Consequently it changes \( O \) state space so that there is no difference between pure and mixed \( S^0 - O \) states. Roughly speaking there is no Stern-Gerlach magnet in the brain and if to decompose the brain into atoms and send them to external analyzer the brain will broke unrestorably and stop to function. Of course this operation - \( B \) measurement can be performed by external observer \( O' \) and verify that MS state is \( \psi_f \) but due to \( O \) destruction in this process \( O \) never can obtain this information from \( O' \). In our opinion obtained paradox shows that in \( O \) basis the operator \( B \) is unobservable and \( |(S^0 - O)^0)\rangle \) final states in selfmeasurement formalism are effectively the same for pure and mixed initial \( S^0 \) state.

Our selfmeasurement formalism corresponds with Heisenberg or algebraic QM, where states manifold defined by observables set, so if some hermitian operator \( B \) is unobservable it reduces initial Hilbert space to some new \( O \) states manifold. To describe \( O \) states manifold we’ll use Hilbert space \( H' \) of observer \( O' \) which include all the possible physical states \( |\psi_1\rangle \) of surrounding world, except \( O' \) internal states. So assuming external-internal states factorization the complete Univers Hilbert space is \( H_T = H_e' \ast H_i' \) tensor product, where \( H_i' \) is \( O' \) internal states subspace. \( H_e' \) space is spanned on Hermitian operators \( Q' \) which are \( O' \) observables set. For observer \( O \) all its Hermitian operators \( Q \) ( except operators describing \( O' \) internal DF) can be obtained mapping \( Q' \) to \( O \) rest frame \( Q = UQ'U^+ \). From the external-internal states factorization it follows \( H_T = H_e \ast H_i \), where \( H_e \) is Hilbert space of outside world and \( H_i \) is Hilbert subspace of \( O \) internal states. In particular \( O' \) observable \( B' \) transforms into \( B \) which as we supposed is unobservable for \( O \). Due to it \( M_I \) - the space of \( O \) internal states \( |O^0\rangle \) is nonequivalent to \( H_i \), but can be decomposed as the tensor product of Hilbert subspaces \([i]\). Each of this subspaces consist of \( O \) eigenstates of given measurement spectral decomposition ( for example \( \mu_z \) eigenstates for CH model) of the same particular eigenvalue : \( M_I = h_1 \ast h_2...h_n \). Unitary states transformations from \( h_i \) to \( h_j \) performed by unobservable \( B \) only and so such unitary transitions are unphysical. Eventually the total \( O \) states \( |\psi^0 \rangle \) manifold is \( M_T = M_I \ast H_e \) relative to \( O \) observer and it describe the observer representation or observer basis \([5]\). In this basis \( |MS^0 \rangle \) states coincide with correspondent mixed states \( \rho_{m}^{\psi} = \delta_{ij} |\psi_i\rangle \langle \psi_j | \) for \( \psi_i \) of \([3]\). It means that at any time for any true observable \( Q \) we have:

\[
\hat{Q} = Tr_{\rho_{p}}Q = tr_{\rho_{m}}Q
\]
where \( \rho_p \) is corresponding pure state and this result corresponds to the state collapse in operational approach.

So due to our R restrictions and \( B \) nonobservability for the interacting observer \( O \) its own states Hilbert space is reduced in comparison with \( O \) states space relative to observer \( O' \) noninteracting both with \( S \) and \( O \). \( O' \) can describe their evolution by Schrodinger equation but \( O \) can’t do it starting from the moment \( t_0 \) when \( S \) starts to interact with \( O \). Consequently \( |MS^0) \) evolution for \( O \) observer coincide with \( \rho_m(t) \) evolution which describe the stochastic quantum jumps from initial to one of final MS states. Due to the appearance of \( S^0 \), \( O \) states entanglement after \( S^0 - O \) interaction in CH model \( O \) representation of MS final states is also equal to tensor product of subspaces characterized by \( \mu_z \) eigenvalue which have each vector of this subspace i.e. it is mixed state corresponding to \( \mu_z \) measurement and collapse.

For the collective solid states with strong selfinteraction the evolution also changes as was discussed above for D spin-spin interactions which probably makes R observation restrictions even more stiff. In the current loop model to measure corresponding \( B \) value means to measure \( N \) electrons interference inside crystal with which this electrons also interact strongly. It’s the same kind of restrictions like in CH model, but it’s even more obvious that nondestructive \( O \) selfmeasurement is impossible. In the next chapter it’s shown that atoms selfinteraction effects can be described by QED radiation decoherence model which results in quite different restrictions.

Of course this consideration isn’t consistent proof of \( B \) nonobservability for observer \( O \). Rather it demonstrates qualitatively that for realistic collective \( O \) systems IT selfmeasurement necessary for the collapse verification obstacles effective information processing and memorization by \( O \). In particular we can’t strictly prove that \( B \) measurement can be only destructive, but for any realistic measurement Hamiltonians it’s impossible to perform it otherwise for large \( N \).

Now we’ll argue that the analogous effects can be derived in some cases even without assuming \( B \) measurement to be destructive. Comparing our model results with Ashtekar hypothesis it seems that \( O \) unobservable operators aren’t particular DFs, but IT which can be constructed of any DF combinations and they defined in fact by \( O \) operators which are measured in the particular experiment and their commutation relations. Let’s consider their connection with \( O \) structure and maximal available information. For this purpose we’ll use CH observer model and suppose that \( O \) consist of \( N_c = m \) chains denoted \( D_c, D'_c, ..., D'^m_c \) and their subspaces are \( h_c, h'_c, ..., h'^m_c \). \( O \) structure defines \( S^0 - D_c \) interaction Hamiltonian \( H_I \) of (2). Due to its asymmetry relative to \( h_s, h_c \) ‘axes’ the information on \( \sigma^0_z \) transferred exactly to \( h_c \), but \( \sigma^0_x \) information corresponding \( S^0 \) IT don’t transferred at all. As the result after \( S^0 - D_c \) interaction finished at \( t_1 \) and they parted no strict measurement by \( O \) can discriminate pure or mixed \( S^0 \) states. But it can be done by the operator \( B \) measurement by the next chain. To perform it at \( t > t_1 \) \( S^0, D_c \) must interact via some Hamiltonian \( H'_I \) with \( D'_c \) which is also \( O \) part. \( D_c \) state at \( t > t_1 \) is \( \psi_f = b_1|B_+\rangle + b_2|B_-\rangle \) of (3) rewrited here as sum of \( B \) eigenstates and so the complete \( O \) state before \( H'_I \) interaction at \( t = t'_1 \) turned on is :

\[
\Psi^1_{MS} = \varphi'_0 = \psi_f |D'_{c0}\rangle ... |D'^m_{c0}\rangle
\]
Then after this $S^0, D_c, D'_c$ interaction finished at $t = t_2$ $O$ state becomes:

$$\Psi^1_{MS} = \varphi'_1 + \varphi'_2 = (b_1|B_+\rangle|D'_c\rangle + b_2|B_-\rangle|D'_c\rangle)|D_0\rangle$$

After it $D'_c$ contains information on $B$ expressed by strict operator $B'$ in $h'_c$ for which $B' = \bar{B}$. Yet in the same time $\sigma^0_z$ information disappears in $h_c$ where $\bar{\mu}_z = 0$ at $t > t_2$ in distinction from true $\bar{\sigma}^0_z$ value which was kept by $D_c$ till $t < t'_1$. So the full information about $S$ state never acquired by $O$, due to $B, \mu_z$ incompatibility.

Yet $B$ measurement by $O$ doesn’t mean that $O$ can discriminate its own (or MS) pure and mixed state. To perform this discrimination the next chain $D^2_c$ should measure $S^0, D_c, D'_c$ state $\varphi'_f$ joint IT operator $B_2$ which form is analogous to $B$ of (4). It can be presented as the operator sum of $N + 1$ members:

$$B_2 = \prod_{j'=1}^{N} \sigma_j^{i'} \sum_{n=1}^{N+1} B^n_n$$

where $j'$ means $D'_c$ elements array, and sum members are:

$$B^n_0 = \sigma_z^0; \quad B^n_1 = \sum_{i=1}^{N} \sigma_z^i; \quad B^n_2 = \sigma_z^0 \sum_{i=1}^{N-1} \sum_{l>i}^{N} \sigma_z^i \sigma_z^l; \quad B^n_3 = \sum_{i=1}^{N-2} \sum_{l>i}^{N-1} \sum_{k>l}^{N} \sigma_z^i \sigma_z^l \sigma_z^k; \quad \ldots$$

and so on to include all uneven number spin flip combinations. This $B_2$ measurement gives IT estimate between $B$ eigenvectors $\varphi'_{1,2}$, but as the result the new entangled state $\varphi^2_f$ appears including in addition $D^2_c$, which IT also must be measured to define MS state. To measure full $O$ state IT’s this measurement sequence should be extended till it includes $N_c = m$ chain, but its IT can be measured only by external $O'$. So due to $O$ finiteness there is always at least one MS IT operator $B_m$ unobservable for $O$. The real meaning of this result needs further study, and here we propose only its tempting interpretation. In our opinion it evidences that even if any $B_j$ measurement can be nondestructive nevertheless , due to $O$ finite rigid structure its selfmeasurement don’t permit to discriminate pure and mixed MS states $|\Psi^0_{MS}\rangle$. For example for $N_c = 2$ operator $B_m = B_2$ can be measured only by $O'$ for which MS state is $|\varphi'_f\rangle$, but $B_2$ is unobservable for $O$ and can’t discriminate MS pure and mixed states. It’s not clear to which extent this result can be general $O$ selfmeasurement property, but we notice that operator $B_m$ acts on all $O$ DFs and to measure and memorize $B_m$ we need at least one more DF which can’t belong to $O$.

3 Radiation Decoherence (RD) and IGUS Memorization

Here we’ll discuss the decoherence model of IGUS which imitate information processing in elementary computer $O$ memorizing quantum signal. We’ll assume that its structure is the finite regular monoatomic crystal lattice $L$. In this case the lattice
excitations and dislocations can store the quantum information. L initial environment $E_f$ is taken to be the electromagnetic vacuum in its ground state $|V_0\rangle$. As the example we’ll consider the inelastic collision of S - neutral particle n wave packet with L in ground state $|L\rangle$. If one of n trajectories $x_2$ crosses L aperture and other $x_1$ lays outside it, such MS can perform the measurement of n position $x$. Suppose that this impact starting at $t_0 = 0$ produces excited state $|L^*\rangle$ which produce dislocation with the new ground state $|L'\rangle$ and accompanied by multiple phonon excitations. This excitations can be dissipated completely via cascade decay of phonons into photons $p \rightarrow p' + \gamma$, which detailed dynamics described in [12]. So at large time the lattice transferred to new ground state $L'$ and all energy excess dissipated to electromagnetic field. Then at large time $t \rightarrow \infty$ the final state of our system and environment becomes :

$$
\phi_f(t) = \phi_1 + \phi_2 = a_1|x_1^n\rangle|L\rangle|V_0\rangle + a_2 \sum c_j|x_2^n\rangle|L'\rangle|j\gamma\rangle
$$

(6)

where $|j\gamma\rangle$ is the localized state of j photons (packets) orthogonal to $|V_0\rangle$, and $c_j$ are their production amplitudes. So O stable states L,L’ memorize information about $x^n$. The analogous final state is produced if n impacts and excites the single molecule $L \rightarrow L'$ memorizing information, which model will be described in forcoming paper.

Beside the possible nonobservability of $L, L'$ interference discussed in the previous chapter the analogous effect can be found for the decohering electromagnetic field $E_f$. QED field measurements are described by Glauber photocounting theory confirmed now experimentally. In its framework all the field observables which can be measured by material detectors $D_\gamma$ are the algebraic functions $F$ of photon numbers operators $\hat{n}(\lambda, \vec{k})$ only [14]. But any hermitian operators with nonzero matrix elements between the states with different photon numbers like $V_0$ and $j\gamma$ can’t be such functions and so their interference is unobservable directly (no interference with vacuum !). So for any true $E_f$ observable $Q_E = F(\hat{n})$ we have :

$$
\langle V_0|Q_E|j\gamma\rangle = 0
$$

(7)

and its effects coincide with mixed state ones. As the result for any true observable $Q$ on $n, L, E_f$ space it follows :

$$
\tilde{Q} = Tr\rho'_p Q = Tr\rho'_m Q
$$

(8)

where $\rho'_p, m$ are the corresponding pure and mixed density matrices, $\rho_m = |\phi_i\rangle\langle\phi_i|$ of (3). Consequently not only observer O identified with L, but also any other O’ can’t discriminate the pure and mixed initial n states in this case. Even if one admits that L, L’ (and $x^n_1, 2$) IT operator $B$ can be measured and any information from $D_\gamma$ accounted by O, it’s impossible to measure the interference terms for the complete state $\phi_f$ of (3).

Note that the initial vacuum state can include arbitrary number of photons non-correlated with L state and it doesn’t change the final result. Despite that this model is oversimplified it can have some relation to the real computer or brain, where the input quantum signal induces the motion of electron currents. This electrons scattered by the crystal lattice excite it and produce via phonon decays soft
(thermal) radiation. In the current loop model described in chap.2, the final state can be analogous to (6), if electron pulses coupled to some stable states $L, L'$ like ferrite memorizing rings. So this information processing and memorization induce the energy dissipation or decoherence, analogously to results of classical information and selforganization theory [2, 16]. In general such $L$ evolution seems quite typical for measurement. First to shift our 'pointer' some energy is needed stored in detector metastable state or particle $n$ energy. Then this energy must be dissipated for information memorization in some $O$ ground states.

The well-known argument is that by means of suitable mirrors array the produced radiation can be reflected, reabsorbed and the initial n-L state restored [15]. This is in fact only approximately true, because absolutely reflecting mirrors are prohibited by the laws of physics and so at slow rate the radiation always penetrate them. It means that even if our IGUS contained inside the mirror box it will function, but more slowly and ineffectively. In case of real mirrors this mirror box must be accounted in the quantization as MS part and we must analyze $E_f$ field penetrating through its walls. Then the multiphoton states of this newly quantized free field $E_f$ outside of box must be regarded. It's reasonable to suppose that asymptotic MS states at $t \to \infty$ will coincide also with (6), so our IGUS will function, but in different regime. If we regard IGUS inside the ideal mirrors box, then it effectively will oscillate between initial and final state and so no L state wouldn’t be memorized finally, which means that our IGUS don’t function properly.

So we can suppose that this model R restrictions demand that any measurement of MS don’t obstacles $O$ information acquisition and memorization. In particular any external $E_f$ measurement permitted, but photons reflection by ideal mirrors to L perturbs $O$ functioning, changing L memorization conditions and so excluded.

Note that in this model the role of decoherence differs principally from Zurek model, where D state collapse is obtained only if observer avoid to measure E operators which are in fact measurable [3]. This procedure of taking the trace over E states result in Improper Mixture paradox and was criticized often [17]. It demonstrates that like in CH model at any time moment at least one IT observable $\hat{B}$ in S-D-E space exists which expectation value $\bar{B}$ coincides with the value for the pure state and differs from the predicted one for the mixed state. So it contradicts with our collapse operational definition. Moreover it follows that in principle it’s possible to restore the system initial state which contradicts with the irreversibility expected for the collapse. In distinction in our MS model the radiation decoherence is necessary and inevitable consequence of the memorization of L states. IT operator $\hat{B}$ of the produced field $E_f$ is principally unmeasurable and for other operators we have relation (8), which in operational approach means the collapse.

Note that in our model, even if initial E is vacuum our excited system $O$ eventually produces E of new kind - photon gas. In connection with it let’s regard the toy-model of E production in the measurement. Suppose that some $O$ (or D) measuring $S$ emits $N_e > 1$ new particles. Then to reconstruct the complete state we need $N_e$ detectors $D_i$. But each $D_i$ emits also $N_e$ particles, which demands another detectors ensemble, etc. So in this case the complete MS state depends on performed measurements and so principally can’t be reconstructed.
4 Discussion

In this paper the measurement models which accounts IGUS information processing and memorization regarded. Real IGUSes are very complicated systems with many DFs, but the main quantum effects like superpositions or decoherence are the same for large and small systems and can be studied with the simple models. Obviously any realistic IGUS can function only in the restricted sector of its atoms Hilbert space. For example, if to decompose processor chip into free atoms it wouldn’t function. Our CH spin chain model indicates that IT selfmeasurement can’t be performed inside this sector. In RD model such measurement is incompatible with the photon dissipation necessary for IGUS functioning and signal memorizing. If we accept as fundamental QM principle :‘No observation without (functioning) observer ’ then it follows that some $O$ operators are principally unobservable for $O$ [18]. So in this approach the collapse problem can be resolved inside standard QM domain taking into account observer quantum properties.

Initially the collapse problem was formulated like following: why in two-slits experiment observer don’t see interfering electromagnetic field radiated from both slits (half and half), but sees the photon appearing at random from right or left slit ? Our suggestive answer is that observer perception also obeys QM laws and due to it the brain reaction on incoming electromagnetic field described by entangled state $\Psi_{MS}$ of (1), or (3) if decoherence accounted. Perception by brain of the photon coordinate is the local strict measurement from which in principle can’t be reconstructed information about field interference between left and right slit.

This CH and RD model results closely connected with operational definition of collapse and in its turn relation between strict measurement and information memorization. We’ve demonstrated that in all these cases for $O$ the information discriminating MS pure/mixed states is principally unavailable. So we can apply this collapse definition for $O$ subjective description of measurement results without contradictions at least for models comparison. This operational definition isn’t sensitive to the ‘problem of event’ [1]. At this level obtained in chap. 2 observer representation is compatible with probabilistic description of measurement results, but can’t derive it directly.

In Relational QM observers are material local objects which are nonequivalent in a sense that the physical world description can be principally different for them [6]. If observer $O$ stops to function (exist), then some other $O'$ world description principally can’t be substituted for $O$ description. Due to discussed R restrictions the Univers Hilbert space $H_T$ reduction to $M_T$ space in $O$ observer representation occurs. Note that MS evolution in $H_T$ is formally reversible and in our models we get irreversible ‘subjective’ evolution observed by $O$ from nonreturnable processes with continuous spectra like S scattering, excitation of $O$ state and photons radiation. Described in chap. 2 $H'_T$ and $M_T$ states manifolds of $O,O'$ observers can be regarded as unitarily nonequivalent (UN) representations, despite their structures needs further mathematical clarification [19]. Such representations appears also in nonperturbative Quantum Field Theory applied already in some microscopic measurement models [20]. In particular QED nonperturbative bremsstrahlung model
of measurement results in collapse-like field evolution which reminds our RD model \[21\].

In Everett+brain QM interpretations eq. \[1\] describes so called observer \(O\) splitting identified with state collapse \[22\]. In this theory it’s assumed that each \(O\) branch describes the different reality and the state collapse is phenomenological property of human consciousness. Obviously this approach has some common points with our models which deserve further analysis. In general all our experimental conclusions are based on human subjective perception. Assuming the computer-brain perception analogy in fact means that human signal perception also defined by \(\bar{Q}_O\) values. Despite that this analogy looks quite reasonable we can’t give any proof of it. In our models in fact the state collapse have subjective character and occurs initially only for single observer \(O\), but as was shown by Rovelli it doesn’t results in any contradictions \[6\]. If it’s sensible to discuss any world partition prompted by QM results it seems to be the border between subject - observer \(O\) which collect information about surrounding objects \(S\) and objects \(S\) which can include other observer \(O'\).

The main conclusion of our paper is that regarded IGUS models evidences that QM (and QED) linear evolution can result in selfmeasurement restrictions which in operational approach can be interpreted as the collapse appearance. Altogether we find independent effects of three kinds which can induce it: \(O\) nondestruction, \(O\) finite rigid atomic structure, and decoherence. Their mutual relations and influence are unknown, but we don’t expect they will suppress each other. Of them the decoherence effects and in particular RD seems to us the practically most important and deserving further detailed study.

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