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Irreversible evolution of a charged spin 1/2 particle analyzed on the basis of subdynamics theory

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ABSTRACT

The time evolution of a charged spin 1/2 particle interacting with a magnetic field is analyzed in the framework of the complex spectral theory, based on Prigogine's principles that provide a rigorous description of irreversibility. A detailed survey of the irreversible relaxation process of the spin 1/2 particle is carried out on the basis of the subdynamics theory. We obtain the results for the Markovian and the non-Markovian evolution of the charged particle.

1. Introduction

Our experience suggests that the symmetry in the time is disrupted and the future and the past play different roles. The world surrounding us has obvious irreversible nature. However, Poincare showed that [1] the description of the irreversibility is impossible on the basis of the classical laws of dynamics, since the latter are reversible in time. The equations of quantum mechanics are reversible too. The description of the physical world on the basis of fundamental classical and quantum theories as defined by the laws of the nature is determined to be time reversible. Difference between the classical description of the nature and those processes in the nature which we observe creates the conflict situation. Therefore the problem of the description of irreversible world on the bases of the reversible equations of classical and quantum physics is raised. I will not discuss the solutions of this problem in classical physics, I will examine the quantum mechanics. First of all it is necessary to note that the question about irreversibility of quantum processes can be examined in connection with the problem of interpretation of quantum mechanics. Briefly, I will examine two most important approaches—Copenhagen and Everett's interpretations.

Copenhagen interpretation of quantum mechanics asserts that we cannot speak about the quantum properties of the system before these properties are measured [2,3]. In other words, quantum theory describes not quantum world but the fact that we can speak about quantum world after measurement. Let the energy of the quantum system has two values E_1, E_2 and φ_1, φ_2 corresponding wave functions. If the system is described by the wave function ψ it is possible to present it in the form of the superposition of the functions φ_1 and φ_2: $\psi = a_1\varphi_1 + a_2\varphi_2$. Before measurement the wave function ψ occupies simultaneously two levels and energy of the system does not have a specific value. Only after the measurement we will obtain the values E_1 or E_2 with probabilities $|a_1|^2$, $|a_2|^2$ respectively. The passage from the "potential possibilities" which are described by the wave function ψ to the "actual realities", which can be measured, is called reduction or collapse of the

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wave function. The physical process leading to collapse is called quantum decoherence. The process of the measurement leads to the abrupt, irreversible change of the state. Any measurement is not a reversed process. Thus, irreversibility appears when the measurement is carried out. In this case the behavior of the quantum system is described by Neumann's postulate of reduction [4] which, however, does not answer the question which *dynamic processes* lead to irreversibility. Thus, in accordance with Copenhagen interpretation of quantum mechanics the observed processes proceeding in the world are caused by our measurements including, for example, the quantum transitions. However, as Prigogine notes, since the quantum transitions are the basic mechanism of chemical reactions it is difficult to agree with the latter assertion. Is it possible to consider the chemistry as the result of our observation? If yes, then who observed the chemical reactions which led to the appearance of life [5]?

Another interpretation of quantum mechanics is proposed by Everett (relative state interpretation) [6]. It was developed in the works [7,8] (many-world interpretation); [9–11] (extension of Everett's concept). Many-world interpretation allows the existence of the infinite numbers of classical realities: each term of quantum superposition corresponds to one classical world. According to the extended Everett's concept the measurement entangles the measured system with the environment, however, linear superposition is not destroyed. Thus, after measurement the linearity of quantum mechanics is preserved. In this case the reduction of the wave function does not occur. However, at the specific moment of time the observer sees only one result of the measurement—the one classical world. This occurs because the consciousness of the observer divides the state of quantum world into the classical realities which he receives independently. The consciousness of the observer subjectively makes the selection of one alternative. The consciousness continuously creates classical reality [10]. Hence follows: the classical world is the illusion, reduction of the wave function is the illusion too, since they appear subjectively in the consciousness of the observer. In the approach, the concepts of the "arrow of time" and irreversibility are rather connected with its subjective feeling of the observer then with the objective property of material itself. It is assumed, the further study of this interpretation will be possible after the construction of the model of "quantum consciousness", which is discussed in the work [11].

Obviously, the approaches examined above contain a subjective, anthropomorphic element. The interpretations contain a basic distinction between the quantum system and the observer. The latter fact is undesirable for the theory since it takes us away from the solution of the basic problem: the determination of the objective laws of the nature (if we believe in the objectivity of the nature). If Copenhagen interpretation is the direct consequence of the insufficient realization of the physical sense of the basic postulates of quantum mechanics, then Everett's interpretation is a natural consequence of them. This situation impels one to the alternative formulation of quantum dynamics which does not appeal to the observer excluding the subjective, anthropomorphous element. In the approach the irreversibility must be represented as the property of material itself and is not defined by the active role of the observer.

In the paper I examine the alternative formulation of quantum dynamics in the framework of the Brussels–Austin group works that has been headed by I. Prigogine for many years. In the works, a possible variant of description of nonequilibrium processes at microscopic level in the frame of the Liouville space extension of quantum mechanics is investigated. The mechanism of the asymmetry of processes in the time which made it possible to accomplish a passage from the reversible evolution to irreversible one was developed. Thus, new irreversible dynamics with the disrupted time symmetry was formulated. The symmetry in the time disrupted as a result of asymmetric nature of the physically permissible states.

At the present moment, it is necessary to continue further development of the Brussels–Austin group approach in the framework of the realistic models of interaction. Then, the irreversible evolution of a charged spin 1/2 particle interacting with a magnetic field is investigated on the basis of subdynamics theory. In the work the survey of the basic principles of the Brussels–Austin group is carried out. In Section 2 the eigenvalue problem is discussed. Perturbative solution of the Schroedinger equation in the framework of complex spectral representation is given. In Section 3 the Liouville formulation of quantum mechanics is represented. The task of the complex spectral representation of the Liouvillian is solved in Section 4. In Section 5 the theory of subdynamics is discussed. The time evolution of the density matrix is determined. The interacting model of positive charged spin 1/2 particle with magnetic field is examined in Section 6. The complex eigenvalue problem for the spin system is solved in Section 7. The expression for the density matrix element describing the irreversible evolution of the charged particle spin system and numerical calculations are obtained in Section 8.

2. Perturbative solution of the Schroedinger equation, complex spectral representation

As the first step, in the framework of Schroedinger equation, I examine as the asymmetry in time can arise. I examine the eigenvalue problem for the Hamiltonian $H = H_0 + \lambda V$

$$H|\psi_\alpha\rangle = \tilde{E}_\alpha|\psi_\alpha\rangle, \tag{1}$$

where H_0 – free Hamiltonian, λV – interaction part, λ – coupling constant. In the conventional case, Hamiltonian H is a Hermitian operator, $\tilde{E}_\alpha$ is a perturbed energy of the state – a real number. It is known that the usual procedure of Eq. (1) solution on the basis of perturbation method can lead to the appearance of the denominators $1/(E_\alpha - E_{\alpha'})$, where E_α, $E_{\alpha'}$ are the energies corresponding to the unperturbed situation. Obviously, the divergences can arise at $E_\alpha = E_{\alpha'}$. The basic question now is – what we can do to avoid the divergences, when $E_\alpha = E_{\alpha'}$. I examine the situation using the simple Friedrichs model [12] (the model is presented closely to the text of the works [13–16]). Despite the fact, that the solution of