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1. Hybridization of Majorana states

Majorana fermions are particles which are their own antiparticles. Quasiparticles with Majorana fermion properties in the form of Majorana zero modes (MZMs) were observed in experiments with quantum wires and vortices in topological superconductors [1]. However, MZMs were spatially separated from each other — one MZM in a superconducting vortex. Obtaining multiple MZMs inside one vortex is of interest but has never been achieved because of technical difficulties. In their experiments, T Liu (Shanghai Jiao Tong University, China) et al. have obtained for the first time convincing evidence of the presence of several MZMs within one vortex in a superconducting crystal film made of topological insulator SnTe [2]. The reaction of the magnetic field to the Majorana states withheld by the vortex in the heterostructure SnTe/Pb was examined using a scanning tunnel microscope. Comparison of the spectroscopic data with the results of theoretical modeling revealed hybridization of several MZMs in a single vortex. Topological quantum systems can find useful practical applications, for instance, in the creation of stable qubits, owing to their resistance against perturbations.

2. Quantum analogue of Arrhenius effect

Quantum tunneling across the barrier in a double potential well was examined in different systems, but it is only the energy level splitting or the dynamics of the ground and first excited state that were observed earlier, although higher excited states are of interest for some molecular and nuclear processes. Their investigation encounters the problem of control over parameters of double-well systems. N E Frattini (Yale University, USA) and his co-authors have created a completely controllable double well in a superconducting chain and verified for the first time the predictions of quantum-mechanical calculations for this case [3]. The superconducting microwave-pumped Kerr–Cat qubit was investigated. In this qubit, a record relaxation time of 1 ms was reached. Spectroscopy of the quantum levels showed a pairwise level approach corresponding to an exponential reduction of the tunnel splitting in the excited states as they sink under a potential barrier. Investigated was a quantum analogue of the Arrhenius law known in chemical kinetics, where it describes the thermal activation of reactions separated by the energy barrier. In the quantum version of the Arrhenius law, where transitions proceed between two potential wells, the transition rate does not change smoothly, but in a stepwise manner, depending on the barrier height. This is explained by the presence of discrete quantum states in the wells. The results of this research can find application in quantum computation.

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3. Wave function collapse

Measurement in quantum mechanics is often interpreted as the wave function collapse, when a system changes from a superposition of states into its one eigenstate (see [4]). Different collapse models were proposed, leading, in principle, to different observational consequences. In these models, nonlinear stochastic terms responsible for the collapse are typically added to the Schrödinger equation. They must trigger the diffusion motion of quantum systems and acceleration of their parts, which can be accompanied by photon emission. However, the corresponding very weak effects of spontaneous radiation have not yet been noticed in experiments. K Piscicchia (E Fermi Research Center and Frascati National Laboratory, INFN, Italy) and his co-authors have performed new computations of the spontaneous radiation spectrum accompanying the wave function collapses in two collapse models: in the Diosi–Penrose model, where the collapse is determined by gravitational interaction, and in the Ghirardi–Grassi–Rimini model with continuous spontaneous localization [5]. Investigated, in particular, was the influence of the non-Markovian evolution of systems. The calculations have shown that for a low energy the above-mentioned two collapse models give different radiation spectra. Moreover, the result of the new detailed calculation differs from the predictions of previous simplified models. The radiation from wave function collapses has already been sought at high energies in the gamma range, but it is only some restrictions on the model parameters that have been obtained. Measurements at lower energies in the X-ray region will be necessary in the future.

4. What plays the role of dynamo in Blandford–Znajek process?

As was shown by R Blandford and R Znajek in the late 1970s, a rotating black hole (BH), possessing a plasma shell in an external magnetic field, can play the role of a unipolar inductor (see [6]). The energy loss here is due to the electromagnetic Umov–Pointing vector flux. The validity of this conclusion was confirmed by many results of numerical simulations both in the framework of magnetohydrodynamic simulations and by the particle-in-cell method. The calculations were typically based on the Kerr–Schild metric allowing a description of flows beyond and inside the event horizon. On the other hand, in the early 1980s, trying to explain the above-mentioned process in the framework of the Boyer–Lindquist metric (it can only be used before the event horizon, and it was just used by Blandford and Znajek), K Thorne and D Macdonald suggested what they thought to be a physically comprehensible model. They introduced a formal membrane located above the very horizon surface. The surface electric current running along such a membrane (i.e., the term $\mathbf{j} \cdot \mathbf{E}$ in the energy balance equation) must have become the source of the electromagnetic energy flux. But here, the following problem arises. The numerical simulations performed by S Komissarov [7] showed that, in a physically adequate statement of the problem (where a black hole rotating in a vacuum with an external magnetic field initially exists, and after that the magnetosphere gets filled with plasma), a region where an energy flux from a BH to infinity has already been formed is limited by two 'inclusion waves,' one of which propagates outwards, and the other, towards the BH. The inner inclusion wave will reach the event horizon infinitely long. And the most important conclusion here is that the surface currents in the inclusion waves are not generated (K Tsyganov and S Bogovalov arrived at the same conclusion for the flat metric [8]), and therefore such a membrane could not have played the role of a unipolar inductor. The source of the Umov–Pointing vector thus remained unclear. As has been shown in the elegant new paper [9], all the questions can be waived provided the inclusion wave is essentially nonstationary. As a result, when approaching the horizon, the inclusion wave fills an increasingly large volume with an electromagnetic field, whose energy in the Boyer–Lindquist metric is known to be negative. The angular momentum of the field opposite to that of the BH will be accumulated in this region. Strictly speaking, the BH itself will lose neither energy nor angular momentum, and the outward flux is explained by the fact that similar fluxes with opposite signs (negative energy and angular momentum) are accumulated in the region behind the falling membrane. In other words, in the energy balance equation, the energy flow in such a nonstationary membrane will be formed by time variation of the electromagnetic field energy density ($\partial\rho/\partial t$). It is possible that the above-described paper [9] has taken the final step in the understanding of the physical mechanism of the Blandford–Znajek process.

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