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1. Search for neutrinoless double beta decay

The CUORE collaboration has presented new results of the search for neutrinoless double beta ($0\nu\beta\beta$) decay of ^{130}Te nuclei [1]. This type of decay has not yet been observed in experiments [2, 3]. It is possible, provided that the neutrino is a Majorana particle, that is, its own antiparticle. The CUORE experiment is being carried out in the underground tunnel at the Gran Sasso National Laboratory (Italy), where a unique refrigerating unit is holding ~ 1.5 tons of material at a temperature of ~ 10 mK for several years. The calorimeter for the search of decays is a 742-kg array of 998 ^{130}Te cubic crystals provided with germanium thermistors. The considerable thickness of the ground screens the detector from the hadron component of cosmic rays, decreasing a hundred times the muon flux, and protection from local gamma-ray emission is partially made of low-background lead found in a sunken ancient Roman ship. Although $0\nu\beta\beta$ decays themselves have not been discovered, it was established that the $0\nu\beta\beta$ half-decay time is over 2.2×10^{25} years, which is today the best constraint for ^{130}Te. From this, there follows in turn a restriction on the effective Majorana mass of the neutrino, $< 90-305$ meV, where the range of values is due to uncertainties in the theoretical calculations. The method of cooling large volumes of substance to ultralow temperatures and of detector screening from the background elaborated for the CUORE experiment may prove to be useful, in particular, for designing quantum computers based on superconducting elements.

2. Propensity rules

As distinct from the selection rule strictly limiting the final states of nuclear and atomic processes, less rigorous propensity rules exist that only point to more probable channels. One of them is the rule of conservation of a hyperfine spin state (sums of spins and projections of spins) under three-particle recombination. This rule has already been confirmed in experiments with an ultracold gas of molecule-forming ^{87}Rb atoms. To verify this rule under other conditions, S Haze (Ulm University, Germany) and his co-authors have examined a similar process of three-particle recombination in a ^{85}Rb atom gas whose properties differ considerably from the corresponding properties of ^{87}Rb [4]. In particular, the rate of three-particle recombination of ^{85}Rb is higher than that for ^{87}Rb by four orders of magnitude. Nevertheless, the propensity rules were experimentally found to also hold for ^{85}Rb in the examined binding energy range from zero to 13 GHz $\times\, h$.

3. Verification of quantum contextuality without loopholes

Verification of the basic elements of quantum mechanics, in particular, those concerning the absence of hidden parameters (the Bell test), requires the absence of so-called loopholes, which might imitate quantum effects by classical ones in view of the imperfection of measurement methods. A supplement to the Bell theorem is the Bell–Kochen–Specker theorem on quantum contextuality, stating that the result of quantum measurements does not exist before the measurement itself but depends on other accompanying measurements (on the context). Possible loopholes in verifying this theorem are the sharpness loophole, detection loophole, and compatibility loophole. Experiments with simultaneous exclusion of the first two loopholes have already been performed before. In a new experiment, P Wang (Tsinghua University and Beijing Academy of Quantum Information Sciences, China) and his co-authors have verified the Bell-Kochen–Specker theorem for the case when all three loopholes were excluded [5]. The electron transitions in entrapped ^{171}Yb$^+$ and ^{138}Ba$^+$ ions were examined through fluorescence observation. Each ion was observed separately by an individual photomultiplier. Measurements show the maximal 100% photon registration efficiency and an over 98% repeatability, which excluded two loopholes. The use of different ions with different sets of levels also allowed excluding the compatibility loophole. The experiment confirmed the Bell–Kochen–Specker theorem, in agreement with the standard Copenhagen interpretation of quantum mechanics. For essential questions in quantum mechanics, see [6].

4. Dark quantum states in a waveguide

G Kirchmair and his colleagues (Institute for Quantum Optics and Quantum Informatics, Austria) have performed an experiment investigating the generation and transfer of 'dark' quantum states of an electromagnetic field between transmon qubits in a microwave waveguide [7]. Qubits play the role of artificial atoms, in which transitions can be accompanied by photon emission. Along with ordinary 'bright' states compatible with the eigenmodes of oscillations in a waveguide, 'dark' states were also excited that had a very weak coupling with the waveguide because of a certain electric field symmetry. Collective 'dark' states have already been obtained in earlier experiments, but coherent control

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over them was impossible. Two pairs of qubits were placed in a waveguide with a rectangular cross section at a halfwave distance between the pairs. Qubits in each pair had a capacitive coupling. The qubit states were controlled by additional electrodes on the side surface of the waveguide. The coherence time of the obtained dark states was 0.6 μs, which exceeded by three orders of magnitude the coherence time of bright states owing to good insulation of dark states from waveguide modes liable to relaxation. Dark states are interesting in that they form a separate subspace of states in which quantum calculations with a long coherence time can be made, and at the same time a way of coherent control over such states exists, which was realized in the new experiments.

5. Record far galaxies

By the present day, many galaxies have been discovered at redshifts $z \sim 9-11$, whose stars had at that epoch an age of $\sim 300-500$ years and therefore must have been born still earlier — at $z \sim 14-15$. On this basis, Y Harikane (University of Tokyo, Japan and University College London, Great Britain) and his co-authors have made attempts to seek galaxies at $z \sim 12-16$ in the COSMOS and SXDS archive databases in the near IR band [8]. These bases rested on observations by different telescopes of celestial regions with a total area of 2.3 square degrees. The method of Lyman-break selection of objects related to absorption in neutral hydrogen was applied, as was the photometric color selection criterion. Two bright galaxies were revealed, called HD1 and HD2, at redshifts $z \sim 12-16.5$ and $z \sim 12-13$. These galaxies had a high UV luminosity and star formation rate, 1.5–2 orders of magnitudes higher than that of our Galaxy, although they are much smaller in size. A spectroscopic method was used to determine the redshift more accurately. The ALMA radio telescopes discovered with a 3.8σ confidence the oxygen [OIII] line in HD1, whose shift corresponds to $z = 13.27$, which agrees with the photometric estimate. Spectroscopic confirmation has not yet been obtained for HD2, and the best fitting in photometry gives $z = 12.3$. It has not been ruled out that the high luminosity of HD1 is partly due to accretion of matter to a supermassive black hole in its center. Another candidate, HD3, has not met all the selection criteria, but photometry gives for it $z \simeq 14.6$. The James Webb space telescope is expected to allow in the near future a detailed examination of early galaxies at large z.

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