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1. Tetraneutron

T Faestermann (Technical University of Munich, Germany) and his co-authors have performed an experiment [1] where the bound state of four neutrons — a tetraneutron ^{4}n — was observed, perhaps for the first time. It has been sought (together with ^{2}n and ^{3}n) since the 1960s, and some indications of the occurrence of candidate events for ^{4}n have been obtained. These results remained, however, ambiguous. In the new experiment, a beam of $^7Li^-$ ions obtained at the accelerator in Garching (Germany) was directed to an $^7Li_2O$ oxide target sputtered onto lithium foil, and the reactions ^{7}Li(^{7}Li,^{10}C)4n were analyzed. The energy spectrum of ^{10}C nuclei escaping at angles of $6-9.5^\circ$ was investigated using a wire proportional counter and an array of silicon detectors. With a 3σ significance, a peak was revealed, which can be interpreted as a ^{10}C nucleus in the first excited state and ^{4}n with a binding energy of 0.42(16) MeV and a half-life of 450 s. An alternative hypothesis that the four escaping electrons are not bound cannot be ruled out yet, but the authors of this study believe that this possibility is less probable, because the observed peak in the spectrum is much narrower than it should be in this case. The reaction ^{7}Li(^{7}Li,^{10}C)4n was already examined earlier at the Kurchatov Institute [2], but at higher energies, due to which the presence of the bound state of ^{4}n could not be found.

2. Quantum spin liquid in an artificial crystal

The state of quantum spin liquid (QSL) predicted theoretically by F Anderson in 1973 has already been observed in ordinary substances. G Semeghini (Harvard University, USA) and their co-authors have created an artificial two-dimensional crystal of 219 ^{87}Rb atoms held in an optical lattice and demonstrated the presence of QSL in it [3]. The lattice consisted of a combination of triangles and hexagons, and the interaction of atoms could be controlled using a Rydberg blockade. Thus, this system was a programmable quantum simulator, different versions of which have already been exploited to analyze quantum effects. The fluorescence visualization method was used to observe chains along which interactions between neighboring atoms occurred; dimer bonds appeared. A QSL state appeared as soon as the number of dimers became four times larger than that of monomers. This effect was predicted by R Verresen, M D Lukin, and A Vishwanath in 2020 [4]. QSL may turn out to be useful for creating topological qubits.

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3. Study of FeSe/$SrTiO_3$

The three-atom-thick monolayer FeSe on a $SrTiO_3$ substrate possesses some interesting properties: its superconducting transition temperature is five times higher than that of bulk samples and it has a record (among iron-based superconductors) superconducting gap width [5]. Replica bands in the photoemission spectrum, which may be due to superconductivity, are a not yet quite clear feature of the FeSe/$SrTiO_3$ spectrum. Two models of replica bands have been proposed, namely, forward scattering of 3d-iron electrons by phonons in $SrTiO_3$ and energy loss by photoelectrons in their interaction with surface phonons. C Liu and co-authors have carried out new studies of $SrTiO_3$ by the method of photoelectron emission with angular resolution and a polarized photon beam from a synchrotron source [6]. The choice of polarization direction allows singling out and examining certain regions of electron bands of the substance and lessens the background effect from other regions. Higher-order replica bands were observed, and their relative amplitude was measured. The amplitude has a higher value than that assumed earlier and depends on orbital directions. The two above-mentioned models separately cannot fully explain these data. The replica bands possibly result from a combination of two or more mechanisms.

4. Exciton propagation in thin semiconductor layers

Semiconductor layers several atoms thick are important for applications in nanoelectronics [7]. Their optoelectronic properties are largely determined by the behavior of excitons, bound systems of electrons and holes. But excitons are electrically neutral and cannot therefore be controlled by an electric field. The method of controlling exciton motion by forming mechanically deformed regions in the substance has recently begun to develop. A change in the exciton propagation under deformation typically causes their motion from low-strain to high-strain regions. R Rosati (University of Marburg, Germany) and his co-authors have examined excitons in WS_2 and WSe_2 monolayers using spatiotemporal photoluminescence observations [8]. Unexpectedly, it turned out that the excitons observed in WS_2 and WSe_2 move in the direction opposite to the expected one, their velocity reaching a record value of 1 μm/0.8 ns. The authors performed a detailed theoretical analysis to conclude that this is due to the presence in monolayers of a counterflow of ‘dark excitons’ not observed directly but affecting the properties of bright excitons. The interaction between bright and dark excitons leads to a counter shift of their energy in a mechanically strained semiconductor, which changes the propagation direction. The control experiment with $MoSe_2$ has confirmed this explanation: in $MoSe_2$, bright excitons move towards the 'correct' side, because the energy levels of dark excitons in $MoSe_2$ lie higher than the levels of bright excitons, and the interaction is weak.

5. Non-Gaussian optomechanics

Progress in experimental technology has recently allowed a study of quantum properties of optomechanical systems at the level of individual photons and phonons. In a new experiment with an optomechanical microcavity, G Enzian (Imperial College London, University of Oxford, and University of Copenhagen) and his co-authors have observed non-Gaussian nonclassical distributions in the cavity phase space occurring with a change in the occupation numbers by one or several phonons [9]. The cavity was a BaF_2 crystal with the resonant mechanical frequency equal to the difference between two neighboring optical frequencies. A pumping laser excited the resonator at the lower optical frequency at room temperature. Then, in an anti-Stokes process, excitation was transferred to higher frequencies and to sound waves. Heterodyne detection was used to characterize finite quantum states of the system. It was found that, with a variation in the phonon occupation numbers, the thermal distribution becomes non-Gaussian. Non-Gaussian processes are of importance in optomechanics for the functioning of supersensitive sensors [10].

6. Objective wave function collapse theories

In quantum mechanics, a problem of measurement exists — the question of how the deterministic Schrödinger equation agrees with a random outcome of quantum state measurement (see, e.g., [11–13]). In the Born and some other quantum mechanics interpretations, quantum randomness in measurements is thought to be one of the fundamental postulates. However, attempts are still being made to construct alternative theories in which the quantum measurement outcome is explained by some dynamic processes. These theories are referred to as objective collapse theories of a wave function. Such mechanisms typically need corrections to the Schrödinger equation, which makes verification of these theories possible in principle. Researchers from the University of Amsterdam (Netherlands) and the Institute of Theoretical Solid State Physics (Dresden, Germany) have investigated the properties of objective collapse theories to conclude that the quantum system evolution allowed by them must necessarily be nonlinear [14]. L Mertens and her co-authors demonstrated this result with the example of a two-level quantum system. In particular, they formulated a minimal nonlinear theory, which reproduces the Born rules for quantum probability amplitudes. For some basic elements of quantum mechanics, see [15, 16].

7. Quantum time arrow

Most fundamental physical laws remain unchanged under time reversal. In this connection, the question arises of how nature chooses a correct direction of physical evolution [17]. One of the popular approaches is the thermodynamic time arrow, in which the direction of time is determined by the direction of entropy growth (an increase in disorder). However, for small systems with quantum properties, a superposition of states is possible with increasing and decreasing entropy, which smears the concept of the thermodynamic time arrow. G Rubino, G Manzano, and C Brukner have shown in [18] that, despite the above-mentioned superposition, the concept of the thermodynamic time arrow can be introduced at the quantum level provided that the dissipative work $W_{\rm diss} = W - \Delta F$ (usual work minus the difference between free energies) associated with summary entropy production is additionally measured. Depending on the relation between this quantity and the temperature T, one or the other direction corresponding to the classical concept of the time arrow is chosen. One direction is chosen for $W_{\rm diss}/(k_{\rm B}T) \gg 1$ and the other direction, for $W_{\rm diss}/(k_{\rm B}T) \ll -1$. However, if $W_{\rm diss}/(k_{\rm B}T) \sim 1$, then the two directions interfere. In this case, no classical (not quantum) analogue of W fluctuations exists.

8. Quantum disagreement theorem

In 1976, in the framework of the classical probability theory, R Aumann proved a theorem (the Aumann disagreement theorem) stating that, under certain conditions, two subjects cannot agree to disagree with each other. P Contreras-Tejada (Institute of Mathematical Sciences, Spain) and co-authors have extended this theorem to the case of quantum events and proved it in two forms, namely, in the formulation resembling that of the classical theorem and assigning a sequence of estimations by subjects of common beliefs [19]. Thus, the Aumann disagreement theorem may be thought of as a general physical principle valid in both the classical and quantum cases. This principle is of importance, in particular, in that it helps rule out quickly some theories aimed at generalizing quantum mechanics.

9. Galaxy without dark matter

Ultradiffuse galaxies are relatively large galaxies with a low surface brightness. Observations have shown that at least some of them may have a small amount of dark matter — much less than ordinary galaxies with the same summary stellar mass. Using the K Jansky Very Large Antenna (VLA) array of radio telescopes, P E Mancera Piña (University of Groningen and the Netherlands Institute for Radio Astronomy) and his co-authors have investigated the kinematics of another similar galaxy AGC 114905 [20] with a spatial resolution nearly 2.5 times higher than before. It has been established that the character of gas disc motion in the galaxy can be described by the gravitational field of only ordinary baryon matter without the necessary presence of dark matter in the halo. The origin of galaxies with a deficit or absence of dark matter is still an enigma. Possibly, a collision of galaxies and a tidal gravitational stripping of layers had taken place [21]. In the central part of the galaxy that survived after the stripping, baryon matter may prevail. The tidal heating leading to stellar orbit expansion has also been considered.

10. Black hole in a dwarf galaxy

M J Bustamante-Rosell (University of Texas at Austin, USA) and her colleagues have measured the black hole (BH) mass in the dwarf spheroidal galaxy Leo I in the local group of galaxies at a distance of 820 thousand light years from the Sun [22]. Both the earlier data and the results of new observations obtained with the VIRUS-W spectrograph from the 2.7-meter telescope of the McDonald Observatory were used. The star velocity dispersion within the angular distance of 75$''$ from the center makes up 11.76 ± 0.66 km s^{-1}. This is indicative of the presence of a massive $(3.3 \pm 2) \times 10^6 M_\odot$ BH in the galactic center, while the hypothesized absence of a BH is ruled out at over 95% significance. The BH mass exceeds the one expected for such a galaxy from extrapolation of the empiric relation for BH mass and galaxies by about two orders of magnitude. Why such a massive black hole resides in a dwarf galaxy is not yet clear. For supermassive black holes, see [23].

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