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1. Search for neutrinoless double beta decay (0νββ)

In some experiments, the hypothetical 0νββ decay of nuclei of different elements was sought and limits from below on the half-decay time $T_{1/2}$ were obtained. Such a decay might occur for the lepton number nonconservation, for example, due to the 'seesaw' mechanism, where the neutrino mass was of Majorana origin. This version of the theory is interesting in the possibility of explaining the small mass of active neutrinos. The currently best limit $T_{1/2} > 3.8 \times 10^{26}$ years for ^{136}Xe nuclei was obtained in the KamLAND-Zen experiment. In the underground AMoRE-I experiment (South Korea), which is a prototype of the full-scale AMoRE experiment, a new improved limit on the 0νββ decay of molybdenum nuclei ^{100}Mo has been obtained [1]. The installation includes 18 molybdenum-containing crystals with 3 kg of ^{100}Mo nuclei at a temperature of 12 mK. In the case of 0νββ decay, the total electron energy, measured by a calorimeter, must be higher than that in normal decay. The anticoincidence method was used to sift background events associated with muons and alpha particles from the decay of alien nuclei. The decays recorded for two years were normal beta decays, while 0νββ decays were not found. These data yield the limit $T_{1/2} > 2.9 \times 10^{24}$ yr. The corresponding effective Majorana mass was $< 210-610$ meV, where the upper and lower values correspond to different nucleus models. Scientists from several Russian scientific organizations are participating in the AMoRE-I experiment.

2. Strong isospin symmetry violation for K mesons

An unexpectedly large isospin symmetry violation in hadron production has been revealed in the NA61/SHINE experiment, which is being performed at CERN. Registered were neutral and charged kaons produced in collisions of argon and scandium nuclei with a center-of-mass energy of 11.9 GeV [2], and $K^{\pm}$ mesons were found to appear $18.4 \pm 6.1\%$ more often the neutral K mesons. The u- and d-quark masses are much smaller than the energy scale of quantum chromodynamics Λ_{QCD}. Due to this, the charged and neutral kaons are related by approximate isospin symmetry (substitution of a d quark for a u quark). The known mechanisms predict isospin symmetry violation by only several percent, which is much smaller than was obtained in the experiment. The reason for such a discrepancy, whose statistical significance is 4.7σ, remains unclear.

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3. Entropy gravitation theory

One conception suggests that a gravitational field does not have a fundamental nature but is rather related to entropy. This approach was developed by E. Verlinde and T. Padmanabhan. It allows, in particular, the derivation of Einstein's equation from statistical initial presuppositions. A new beautiful theory of the kind has been proposed by G. Bianconi (Queen Mary University of London, Great Britain) [3]. In this theory, the metric at each point of spacetime is interpreted as a density matrix or a quantum operator. The action functional is determined by quantum relative entropy between the manifold metric and the metric induced by the matter field. Also applied is a topological description of matter fields in accordance with the Dirac–Kähler formalism, and a new G field is introduced. Within this approach, Einstein equations with a zero or small cosmological constant dependent on the G field are reproduced in some limit. It is possible that G. Bianconi's theory may in the future be experimentally verified on the basis of small corrections that distinguish it from the standard General Theory of Relativity.

4. High-temperature superconductivity in a copper-free compound

High-temperature superconductivity was discovered in 1986 in cuprates — layered compounds containing copper. S.L.E. Chow, Z. Luo, and A. Ariando (National University of Singapore) have discovered atmospheric-pressure high-temperature superconductivity in a compound which is not a cuprate but has a similar structure [4]. The superconducting state at a temperature of $\simeq 40$ K and atmospheric pressure was observed in thin films of (Sm-Eu-Ca-Sr)NiO_2 with hole doping. V.L. Ginzburg (a 2003 Nobel Prize winner and a 1938 graduate of the MSU Physics Department) believed the study of high-temperature and room-temperature superconductivity to be one of the most topical problems in physics, [5] and layered structures to be the most promising candidates to manifest these properties [6, 7].

5. Turbulence in two-dimensional Bose–Einstein condensate

M. Zhao, J. Tao, and I.B. Spielman (University of Maryland, College Park and National Institute of Standards and Technology, USA) have found that the statistical properties of turbulent pulsations in a 2D Bose–Einstein condensate of rubidium atoms correspond to the universal law discovered in

1941 by A.N. Kolmogorov (Professor at MSU beginning in 1931) [8]. Turbulence in Bose–Einstein condensates had already been observed earlier, but the correlation velocity functions had not been measured. In the new experiment, the condensate of 2×10^5 atoms was initially in the state $|F = 1, m_F = 1\rangle$ of hyperfine splitting. To measure velocities in small regions of the condensate using laser pulses, regions of the $|F = 1, m_F = 0\rangle$ state were created, and after 0.3 ms their displacements were traced by absorption measurements to an accuracy of μm. The obtained structural velocity functions $S_2(l) \propto l^{2/3}$ are consistent with the Kolmogorov spectrum. Thus, in a system with essentially quantum properties, the turbulence law is realized, typical of classical (not quantum) systems. The obtained results were successfully reproduced in modeling turbulence on the basis of the Gross–Pitaevskii equation.

6. Magnetic analogue of Lyddane–Sachs–Teller (LST) relation

The dielectric LST relation, which relates statical and dynamic dielectric permeability of material (resonance frequencies of a crystal lattice), was discovered in 1941. V. Rindert (Lund University, Switzerland) and his co-authors have predicted theoretically and demonstrated experimentally a magnetic analogue of the LST relation [9], relating the magnetic resonance frequencies of material to its static permeability. The validity of the 'magnetic LST relation' was demonstrated using terahertz spectroscopy for a semiconductor — an iron-doped gallium nitride GaN crystal. The magnetic resonance was continuously measured depending on frequency and with full information on polarization. The permeability function was analyzed to demonstrate accordance with the magnetic LST relation.

7. Iron-helium compounds

At high pressure, noble gases are no longer inert, changing their electronegativity and forming various compounds. Xenon compounds with iron and other substances are known, but helium compounds are not well known. H. Takezawa (University of Tokyo, Japan) et al. have investigated the reaction of solid iron with helium in a diamond anvil heated to 2820 K at pressures of 5–54 GPa [10]. Synchrotron X-ray diffraction showed the occurrence of face-centered cubic (fcc) and distorted hexagonal closely packed (hcp) phases, the volumes of whose elementary cells were much larger (up to 48%) than those of pure iron at the same pressure. The calculations by the density functional method showed that the increase in the volume is explained by the introduction of helium atoms into the interstitial sites and by a possible formation of $FeHe_x$ compounds with $x = 0.05-0.48$. Upon releasing pressure, the fcc and hcp phases survived, but the content of helium in the former one decreased. The method of secondary iron mass spectrometry in the extracted Fe–He sample confirmed the results of X-ray structural measurements. This study states that Earth's core, which mainly consists of iron, may be a reservoir of primordial helium.

8. New observations of ALMA radio telescopes

Dust in a distant quasar. The influence of radiation from active galactic nuclei containing supermassive black holes (BHs) on the heating of the interstellar medium of host galaxies and on their observed properties is of great interest. The ALMA radio telescopes were used to examine the spatial distribution of dust in the host galaxy of quasar J2348-3054 at redshift $z = 6.9$ containing a BH of mass $(0.6-2.0) \times 10^9 M_\odot$ [11]. Observed in the galaxy is an optically thick dust component at a distance of less than 216 pc from the center with a temperature of 88 ± 2 K. According to the calculations, the dust heating was due to radiation from the active nucleus. It was assumed earlier that the dust medium in this galaxy is optically thin, which was ≈ 3.6 times larger than the estimated star formation rate. The data from observations may help in understanding quasar properties at large z.

Coalescence of galaxies. In the hierarchic picture of galaxy formation, galaxies grow as a result of coalescence with neighboring galaxies and due to accretion. The coalescences induce flares of star formation and initiate galactic nucleus activity upon gas fall on the central BHs. Of particular interest is the epoch of redshifts $z \sim 3-4$, when these processes were most efficient. Using observational data from the J. Webb Space Telescope and the ground-based ALMA radio telescopes, W. Wang (Center of Astronomy of Heidelberg University, Germany and California Institute of Technology, USA) and his co-authors have revealed in four radio galaxies at $z \approx 3.5$, from observations of oxygen and nitrogen lines, from two to five companion objects at a distance up to 18 kpc from their centers, which are probably absorbed small galaxies [12]. Measurement of velocity gradients in two of them showed the presence of rotation, that is, the coalescing companion galaxies might have been discs.

9. 41-s radio pulsar

Several sources of cosmic radio pulses with periods from several minutes to several hours, called 'long-period transients,' have been discovered in recent years. They possess some common properties with normal pulsars, which have periods from milliseconds to seconds, but their radiation cannot be explained by rotation because of their small periods. An object with intermediate properties — the radio pulsar PSR J0311 + 1402 — with pulses of 0.5 s and a period of 41 s was detected for the first time by the Australian radio telescope ASKAP [13]. The pulsar is in our Galaxy at a distance of 0.8–1.1 kpc from Earth and has the radiation polarization and spectral index typical of pulsars. At the same time, this pulsar is located below the 'Death Line' — the curve on the $P-\dot{P}$ diagram (period and the period decrease rate), where e^+e^- pair formation and radio emission generation are expected to cease. The discovery of PSR J0311 + 1402 suggests the existence of an earlier unknown population within such an intermediate period, missed by traditional methods of pulsar detection. The possibility of finding pulsars much lower than the 'Death Line,' in the so-called 'Death Valley' was theoretically substantiated in papers [14, 15], where, notably, the criteria of cascade particle generation were refined. The formation of neutron stars under various conditions was also considered in the work of researchers from the Sternberg State Astronomical Institute (GAISh) of MSU in the framework of population synthesis [16]. The detection of intermediate radio transients will provide insight into the processes of neutron star formation and evolution.

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