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1. Ultraperipheral nuclear collisions at Large Hadron Collider (LHC)

If atomic nuclei do not overlap geometrically during a close flyby of two relativistic ions, then strong interactions of nucleons are impossible, but the nuclei can nevertheless be excited by the mutual electromagnetic field and undergo dissociation. Ultraperipheral collisions of ^{208}Pb$-^{208}$Pb nuclei at a center-of-mass energy of 5.02 TeV have been investigated in the ALICE experiment at the LHC, and the copper-to-gold nuclear conversion in photonuclear reactions have been observed for the first time [1]. Hadron calorimeters were used to measure cross sections of reactions with up to three protons and three neutrons emitted from a ^{208}Pb nucleus. In such collisions, different isotopes of thallium, mercury, gold, and copper are formed. The theoretical predictions of the RELDIS model have turned out to differ sometimes from the results of the experiment. For instance, for processes with the emission of one and two protons, the model reaction cross section is smaller by $\sim 17-25\%$. The obtained new data may possibly help to improve the theoretical description of nuclear collisions. For the fundamental problems of nuclear physics, see [2].

2. Search for dark matter (DM) particles

Although the mean DM (hidden mass of the Universe) density is 5.6 times higher than the mean density of ordinary baryon matter, the composition of DM is still unknown. Probable candidates are new elementary particles beyond the Standard Model, and in some experiments the effects of interaction between DM particles and a detector substance are sought. Presented are the first results of the search for light ($\leqslant 1$ GeV) DM particles in the underground XENONnT (Gran Sasso, Italy) experiment, where the detector working medium is liquid xenon [3]. Since for the case of light DM particles the signal of direct scintillation photons is small, the search was concentrated on observing the secondary scintillation emission of electrons which may have been emitted in the interaction with DM particles. Several DM models were considered: particles with masses from 10 to 10^6 keV, interacting with electrons via mediator particles, and bosons (axionlike particles or dark photons). DM particles have not yet been registered, but, for the above-mentioned models, constraints on the interaction cross section and on the coupling constant with electrons have been obtained. These constraints confirm, and in some parameter ranges improve, the constraints found in previous experiments. For another principle of detecting axionlike DM, see [4].

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3. Gauge gravitation theory

The construction of the quantum gravitation theory was started as far back as 1935 by M.P. Bronshtein [5]. Since then, several approaches have been proposed to the quantization of a gravitational field and to its unification with fields of the Standard Model (SM) of elementary particles, but this problem has not yet been solved completely. M. Partanen and J. Tulkki (Aalto University, Finland) have developed an extension of TEGR (teleparallel equivalent of the General Relativity Theory) theory, allowing gravitation to be considered a gauge field and involving all the SM fields [6]. In their work, they used compact finite-dimensional gauge symmetry groups and an eight-spinor formalism. Feynman diagrams are presented for graviton interaction with ordinary particles, resembling particle interactions in the SM, and the renormalizability of the formulated theory is shown in the one-loop approximation. If renormalizability survives in all perturbation theory orders (this has not yet been proved), the new theory will be able to describe high-energy processes.

4. High-pressure hydrates

Water and hydrogen are known to form various stoichiometric compounds at high pressures. The host molecules of H_2O make up a sublattice resembling pure ice, whereas H_2 molecules occupy intermediate positions or substitute for H_2O. A transition between the C2 ($(H_2O)H_2$) and C3 ($(H_2O)(H_2)_2$) phases has already been recorded in the range of 44–60 GPa in previous experiments with laser heating, but the structural information on C3 remained limited. A.F. Goncharov (Carnegie Institute, USA) and his co-authors have performed a new experiment under conditions of excess hydrogen, in which a transformation from C2 to C3 was observed at room temperature in the pressure range of 47–103 GPa, and after decompression C3 remained metastable up to 40 GPa [7]. X-ray diffraction and Raman spectroscopy measurements were performed in laser-heated diamond cells. It turned out that at a pressure of 69 GPa the structure of the phase C3 is cubic with the space group $Fd\bar{3}m$. The authors' 'first-principles' calculations predict pressures at which C2 and C3 remain stable or metastable.

5. 21-cm neutral hydrogen line in epoch of reionization

Hydrogen reionization in the Universe that took place at redshifts $z \sim 6.4-15$ was caused by radiation from the first stars and black holes, but the details of these processes are not yet completely clear, especially in connection with J. Webb observations of an unexpectedly large number of early galaxies (see review [8]). One of the methods of studying the epoch of reionization is to measure the relic radiation absorption on the 21-cm neutral hydrogen line. This absorption cannot now be reliably detected because of strong backgrounds, but some constraints on its value have been obtained. New constraints of this kind are presented in two observation problems. Using a LOFAR antenna grating, an upper limit on the absorption power of $(146.61\ \mathrm{mK})^2$ has been obtained for the first time at $z = 9.16$ and the wave number $k = 0.05\ \mathrm{Mpc}^{-1}$ from the direction to the source 3C196, where the background radiation shows a cold spot [9]. And, using the Murchison Widefield Array (MWA), the strongest value was obtained in all directions — $(30\text{–}40\ \mathrm{mK})^2$ at $z = 6-7$ and $k \approx 0.13\ \mathrm{Mpc}^{-1}$ [10]. The presented data indicate the presence of a heated intergalactic medium at redshifts $z = 6.5-7.0$, which limits the proposed 'cold reionization' models.

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