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1. Charge radius of carbon nuclei

The charge radii of atomic nuclei are typically measured using electron scattering methods and spectroscopy of ordinary and muonic atoms, in which an electron is replaced by a muon. For the proton charge radius in ordinary and muonic atoms, the results diverge at a confidence level of 7σ, and this difference has not yet been explained [1]. For nuclei heavier than helium nuclei, except for carbon nuclei, the measurements are much less precise. P. Müller (Technical University of Darmstadt, Germany) and his co-authors have performed new measurements of the root-mean-square charge radius of ^{13}C nucleus using laser spectroscopy with an accuracy six times higher than that in previous experiments exploiting the electron scattering method [2]. The $2^3S \to 2^3P$ transitions between the components of hyperfine splitting of the electron levels of $^{13}C^{4+}$ ions were studied. The obtained value at the level of 3σ diverges from the results of previous measurements for muonic atoms. The reason for this divergence has not yet been clarified either, possibly because of the specificity of the interaction of muons in the case of violation of lepton universality or because of other effects beyond the Standard Model, although some experimental errors may have remained unaccounted for.

2. Violation of Kirchhoff radiation law (KRL) in metamaterials

The possibility of KRL violation (the ratio of radiative and absorptive capabilities of a substance is equal to the universal function of frequency and temperature) in Weyl semimetals and other systems has been predicted in several papers. Until recently, an indication of a weak violation of this law was only obtained for InAs-based compounds in a narrow frequency range. Z. Zhang (Pennsylvania State University, USA) et al. have become the first to demonstrate a strong KRL violation in a metamaterial [3]. In a gradient-doped sample consisting of five layers of $In_{0.53}Ga_{0.47}As$ on a gold substrate, the IR radiation propagation at different angles in a magnetic field was observed. A violation of KRL was recorded in a wide range of radiation angles and frequencies, and in some cases the difference between the emissivity and absorptivity at the same frequency reached a record value of 0.43. The authors explained the observed phenomenon by the presence of electromagnetic Berreman modes. This effect can find application in sensors and also for control of heat flows and for energy conversion. Metamaterials that have recently found wide application were first considered theoretically in papers of V.G. Veselago (Lebedev Physical Institute) in 1967 [4, 5].

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3. Topological extension of Landau phase transition theory

The Landau theory of phase transitions successfully describes many observed phenomena. It is based on the expansion of free energy in powers of the quantity called the order parameter. A change in the order parameter, which can be of various natures, is associated with transitions between phases. C. Sun and J. Maciejko (University of Alberta, Canada) have extended the Landau theory of phase transitions to the case where the order parameter is a multicomponent quantity in an irreducible representation of the symmetry group and has a nontrivial topological structure [6]. C. Sun and J. Maciejko demonstrated this approach using the example of the theory of superconductivity with tetragonal symmetry and attractive interaction, including two partial waves. The study of the Ginzburg–Landau equation showed that the order parameter acquires a Berry phase after a cyclic evolution. Ways to experimentally verify the generalized theory are also presented in [6].

4. Spin noise spectroscopy in halogenide perovskite crystal

V.O. Kozlov (St. Petersburg State University) and his co-authors have become the first to apply the spin noise laser spectroscopy method [7] to study an anisotropic semiconductor crystal — a halogenide perovskite $MAPbI_3$ [8]. Spin fluctuations of a medium (magnetization fluctuations) due to magnetic moment precession in a magnetic field with random phases were detected through observation of Faraday rotation polarization noise. A probing polarized light beam from a laser passed through a crystal and was recorded by a polarimetric receiver. Birefringent $MAPbI_3$ single crystals were grown by counterdiffusion in a gel. The energy of the probing radiation photons was 1.55–1.62 eV, which is much lower than the forbidden $MAPbI_3$ bandwidth. This ensured observation of polarization fluctuations of transmitted light with a negligible disturbance of the medium. A record length of time of spin coherence — nearly 4 ns — was shown, anisotropy of the g-factor of spin carriers was measured, and spontaneous crystal twinning (the occurrence of two different spin subsystems) was revealed in the experiment. The equipment of the Nanophotonics resource center of the Scientific Park of St. Petersburg University was used in the work. Halogenide perovskite semiconductors have recently attracted much attention, for the most part due to the prospects for their use in photovoltaics and spintronics.

5. Sign of integral Sachs–Wolfe (ISW) effect

According to the Rees–Sciama effect, cosmic microwave background radiation (CMB) should cool down when passing through an object of the large-scale structure of the Universe at the nonlinear stage of its evolution. But in the modern Universe, the ISW effect associated with the change in the gravitational potential under the influence of dark energy should prevail in magnitude. The ISW effect should lead to an increase in the temperature of the CMB that has passed through galaxies and to cooling of the CMB that has passed through voids. However, beginning in 2023, some observations at the $> 3\sigma$ confidence level have revealed an opposite picture: the CMB cools down when passing through galactic halos at small redshifts. A new confirmation of this phenomenon was reported in papers [9, 10]. F.K. Hansen (University of Oslo, Norway) et al. have analyzed the Planck satellite data on CMB fluctuations compared to the map of nearby voids from the 2MASS survey [9]. At the level of $2.7-3.6\sigma$, the temperature of the CMB that has passed through voids turned out to be heightened, contrary to the theoretical predictions. As was shown by J.I.D. Feldman (National University of Cordoba, Argentina) and their co-authors, the decrease in the temperature of the CMB that has passed through individual galaxies in filaments (large-scale threadlike structures), which was revealed earlier at redshifts $z < 0.02$, also occurs for filaments as a whole at $z = 0.02$–0.04 [10]. These results indicate that the ISW currently has a sign opposite to that expected. Considered as an explanation was the interaction of the CMB with dark matter or a quick evolution of gravitational potential in some models of dark energy and modified gravitation.

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