Physics – Uspekhi 64 (1) 106 – 107 (2021)

PACS number: **01.10.–m**, **01.30.–y**, **01.90.+g**

Physics news on the Internet (based on electronic preprints)

Yu N Eroshenko

DOI: https://doi.org/10.3367/UFNe.2020.12.038900

1. Detection of CNO neutrinos from the Sun

Star's energy comes from nuclear fusion reactions that also produce neutrinos. In the Sun, 99% of the energy is released in the thermonuclear pp cycle, producing neutrinos, which were registered as far back as the early 1970s. Neutrinos born in another thermonuclear cycle in the Sun, the so-called CNO (carbon-nitrogen-oxygen) cycle only yielding 1% of the energy, was first recorded in the Borexino experiment carried out at the Gran Sasso National Laboratory in Italy [1]. These neutrinos had not been observed before because of the low interaction rate and the presence of backgrounds. In the CNO cycle, C, N, and O nuclei are catalyzers, which was shown by Bethe and Weizsacker in the 1930s. The Borexino detector is located in a low-background mountain tunnel. It contains 280 tons of scintillator observed by 2212 photomultipliers. Registered are flashes of light from neutrino scattering by electrons. The main source of the background in the CNO neutrino energy range is the decay of ^{11}C and ^{210}Bi nuclei. The thermal stabilization of the detector performed in 2016 made it possible to decrease convection and to estimate more accurately the signal from ^{210}Bi. After that, it became possible to identify with $\simeq 5\sigma$ significance the signal from neutrinos produced in the CNO cycle. The results of measurements agree perfectly with the standard solar model and with the Mikheyev–Smirnov–Wolfenstein mechanism of neutrino oscillations. Thus, the neutrino spectroscopy of the Sun completely ended with registration of CNO neutrinos. Helioseismology and measurements of solar matter opacity show somewhat different data on metallicity (the content of elements heavier than helium), which is known as the 'solar metallicity problem'. The CNO neutrino data are as yet consistent with both low- and high-metallicity solar models, but further observations are needed to solve the problem. For experiments with solar neutrinos, see [2].

2. Diffusion in an ultracold Fermi gas

In ultracold Fermi gases, the free path l of atoms is determined by the distance between them, and the particle velocities $v \sim \hbar/(ml)$ are restricted by the uncertainty principle; therefore, at low temperatures, the diffusion coefficient must reach the value $D \sim \hbar/m$. Such universal behavior of diffusion has already been observed earlier in ^{4}He, but for atomic Fermi gases the experimental situation remained ambiguous. P B Patel (Massachusetts Institute of Technology, USA) and co-authors investigated diffusion in the gas of ^{6}Li atoms and confirmed the universality of D at low temperatures [3]. The optical trap was a hollow light tube bounded on both sides by slab laser beams. In this trap, the gas was highly uniform. Modulating the intensity of one of the slab beams by the sinusoidal law, one could generate sound waves in the gas that were observed directly by the absorption method. The character of wave attenuation determined the diffusion coefficient at different sound frequencies. At high temperatures, D showed the Boltzmann temperature dependence $\propto T^{3/2}$, while at temperatures below the superfluid transition temperature the universal quantum limit $D \sim \hbar/m$ was attained. The present study can clarify both a number of processes in superconductors and the properties of matter in merging neutron stars.

3. Efimov effect near the Feshbach resonance

In the 1970s, V N Efimov predicted theoretically [4] the presence of an infinite number of bound states of three boson particles. The existence of these 'Efimov states' has already been experimentally confirmed. X Xie (University of Colorado, USA) and co-authors investigated the inelastic scattering of an ultracold gas of ^{39}K atoms near a Feshbach resonance with an intermediate atomic coupling strength [5]. The experimental conditions allowed the Efimov effect to be well isolated from van der Waals interaction effects. The character of scattering depends on the relation between the effective scale of a two-particle resonance and the particle scattering length, as well as on the gas temperature. An examination of the parameter space showed four distinct features, i.e., maxima in the three-body recombination coefficient. The positions of three of these features correspond to within an accuracy of 10% to the universal ratios predicted on the basis of the Efimov theory, while the fourth feature does not satisfy the universal dependence.

4. Direct visualization of dark excitons

Excitons are bound states of electrons and holes kept together by Coulomb forces. If an electron and a hole belong to the same valley of the conduction band, then the excitons are called bright, and if they belong to different valleys, they are called dark. Dark excitons cannot absorb light themselves, since the electrons and holes in them have different momenta. J Madeo (Okinawa Institute of Science and Technology, Japan) and co-authors investigated dark excitons in a two-dimensional film of a tungsten diselenide semiconductor one molecule thick using photoelectron spectroscopy with angular resolution [6]. The events of electron escape from a WSe_2

Yu N Eroshenko Institute for Nuclear Research,
Russian Academy of Sciences,
prosp. 60-letiya Oktyabrya 7a, 117312 Moscow, Russian Federation
E-mail: erosh@ufn.ru

Uspekhi Fizicheskikh Nauk **191** (1) 110 (2021)
Translated by M V Tsaplina

monolayer under the action of a linearly polarized extreme ultraviolet radiation beam were resolved in time (this was necessary as the excitons are short-lived), momentum, and energy on a unified experimental platform. Both the dark excitons themselves and their interaction with bright excitons at different energies and momenta were observed. It was established that the number of dark excitons exceeds that of bright excitons. Dark excitons and the 'exciton liquid' they form may possibly help in creating information and energy transfer devices on microscales. For excitons in semiconductors, see [7–9].

5. Search for an additional parity violation in relic radiation

The search for effects beyond the Standard Model of elementary particles in the data from cosmological observations is of great interest. An additional parity violation might affect the character of relic radiation polarization. The polarization rotation has already been noticed by the Planck collaboration, but the result had a serious uncertainty. Y Minami (High Energy Accelerator Research Organization KEK, Japan) and E Komatsu (Max Planck Institute for Astrophysics, Germany and University of Tokyo, Japan) applied a new method of data processing proposed earlier by Y Minami, E Komatsu, and their colleagues, which provided a factor-of-2 smaller uncertainty [10]. The method makes use of microwave galactic emission. The telescope calibration error α is contained in the data on both relic radiation and galactic emission. And the additional polarization rotation angle β can only belong to relic radiation. The decomposition in multipoles and the allowance for the difference in the frequency spectra allow distinguishing between the two contributions. It was found with good accuracy that α is close to zero, and for β the value of 0.35 ± 0.14 deg was found. Thus, the polarization plane rotation, revealed with a statistical significance of 2.4σ, may testify to parity violation beyond the Standard Model, i.e., to a new physics in the early Universe. The rotation may be caused, for example, by an axion-like field associated with dark matter or dark energy. However, further investigations are needed to confirm the obtained result. For the prospects of new physics beyond the Standard Model, see [11, 12].

References

1. The Borexino Collaboration, Agostini M et al. *Nature* **587** 577 (2020); https://doi.org/10.1038/s41586-020-2934-0
2. Derbin A V *Phys. Usp.* **57** 512 (2014); *Usp. Fiz. Nauk* **184** 555 (2014)
3. Patel P B et al. *Science* **370** 1222 (2020); https://doi.org/10.1126/science.aaz5756
4. Efimov V *Phys. Lett. B* **33** 563 (1970)
5. Xie X *Phys. Rev. Lett.* **125** 243401 (2020); https://arxiv.org/abs/2008.00396
6. Madeo J *Science* **370** 1199 (2020); https://doi.org/10.1126/science.aba1029
7. Glazov M M, Suris R A *Phys. Usp.* **63** (11) (2020); *Usp. Fiz. Nauk* **190** 1121 (2020)
8. Durnev M V, Glazov M M *Phys. Usp.* **61** 825 (2018); *Usp. Fiz. Nauk* **188** 913 (2018)
9. Lozovik Yu E *Phys. Usp.* **61** 1094 (2018); *Usp. Fiz. Nauk* **188** 1203 (2018)
10. Minami Y, Komatsu E *Phys. Rev. Lett.* **125** 221301 (2020); https://doi.org/10.1103/PhysRevLett.125.221301
11. Troitsky S V *Phys. Usp.* **55** 72 (2012); *Usp. Fiz. Nauk* **182** 77 (2012)
12. Kazakov D I *Phys. Usp.* **62** 364 (2019); *Usp. Fiz. Nauk* **189** 387 (2019)