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PHYSICS OF ULTRACOLD ATOMS AND THEIR APPLICATIONS

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Work on the physics of ultracold atoms in Russia

In December 2017, the regular All-Russian Conference ‘Physics of Ultracold Atoms’ was held. Several tens of Russian scientists from major scientific centres of the country, as well as a number of leading foreign scientists took part in the Conference. The Conference topics covered a wide range of urgent problems: quantum metrology, quantum gases, waves of matter, spectroscopy, quantum computing, and laser cooling. This issue of Quantum Electronics publishes the papers reported at the conference and selected for the Journal by the Organising committee.

N.N. Kolachevsky, A.V. Taichenachev

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Crossover from an atomic Fermi gas to a molecular Bose gas in a 2D system

V.B. Makhalov, A.V. Turlapov

Abstract. **The results of experimental and theoretical studies of a smooth crossover from a kinematically 2D Fermi gas of ultracold atoms into a Bose gas of molecular dimers are compared. The main attention is paid to the measurements and calculations in the zero-temperature approximation. The discrepancies between the results are discussed along with the questions that remain still open.**

Keywords: *laser cooling, low temperatures, Bose–Einstein condensation, Fermi gas.*

Laser cooling and trapping of matter [1–3] are widely used in fundamental and applied research: standards of frequency and time have been created on the basis of ultracold atomic gases [4, 5]; the interference of de Broglie waves of atoms has made it possible to perform highly accurate measurements of angular and linear accelerations, including gravity acceleration [6]; gyroscopes based on ultracold atoms are being developed [7, 8]; the gas of ultracold atoms excited to Rydberg states [9, 10] is a promising medium for the implementation of quantum informatics algorithms [11].

In experiments with ultracold gases of Bose and Fermi atoms, a number of effects were first observed, the mathematical models of which form the basis of quantum physics, for example, the Fermi pressure [12] and Bose condensation [13]. To date, a wide range of experiments have been performed with Bose condensates [14–16] and Fermi gases [14, 17, 18].

Rearranging the interactions by means of the Fano–Feshbach resonance [19] made it possible to adiabatically transform the gas of Fermi atoms into a Bose condensate of molecular dimers [14, 17]. From the theoretical viewpoint, a similar crossover was considered in the late 1960s for excitons [20] and electrons [21] and later for quarks [22], though only recently it was implemented in a gas of ultracold Fermi atoms [23] for 3D systems, and then for 2D ones [24].

Kinematically, 2D quantum systems attract attention due to the role of fluctuations, which increases with decreasing dimensionality. On the one hand, this complicates the description of such systems, and on the other hand, makes their physics more interesting [25, 26]. Two-dimensional fermion systems include an electron gas in layered systems, such as heterostructures [27] and high-temperature superconductors [28], ^{3}He films [29], and a so-called nuclear lasagne of neutron stars – a region with predominant 2D kinematics, which possibly limits the pulsar rotation period [30].

In this paper we discuss the results of studying the crossover between the fermion and boson states of a two-dimensional Fermi gas, that is, the crossover between the Bardeen–Cooper–Schrieiffer state and the Bose–Einstein condensate (BCS–BEC crossover). We consider a gas of Fermi atoms in two equally populated spin states interacting through s-wave scattering, the magnitude of which can continuously vary within the widest possible limits. The previously published experimental data and theoretical calculations are compared. The main attention is focused on measurements and calculations in the zero-temperature approximation. In experiments [24, 31, 32], measurements were conducted in an ultracold gas of Fermi atoms ^{6}Li trapped in a disk-like potential whose shape is close to parabolic:

$$V(\boldsymbol{x}) = \frac{m\omega_z^2 z^2}{2} + \frac{m\omega_\perp^2 (x^2 + y^2)}{2}, \tag{1}$$

where m is the mass of atom; and ω_z and $\omega_\perp$ are the potential frequencies. The retention along the z axis is much ‘stronger’

V.B. Makhalov Institute of Applied Physics, Russian Academy of Sciences, ul. Ulyanova 46, 603950 Nizhny Novgorod, Russia;
e-mail: vasiliy.makhalov@appl.sci-nnov.ru;
A.V. Turlapov Institute of Applied Physics, Russian Academy of Sciences, ul. Ulyanova 46, 603950 Nizhny Novgorod, Russia;
N.I. Lobachevsky State University of Nizhny Novgorod, prosp. Gagarina 23, 603950 Nizhny Novgorod, Russia;
e-mail: turlapov@appl.sci-nnov.ru

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