Pis'ma v ZhETF, vol. 124, iss. 3, pp. 216 – 218

The effect of pressure on the splitting of the superfluid transition in ^{3}He in nematic aerogel

V. V. Dmitriev[+], *D. V. Petrova*[+*], *A. A. Soldatov*[+1)], *A. N. Yudin*[+]

[+]*P. L. Kapitza Institute for Physical Problems of Russian Academy of Sciences, 119334 Moscow, Russia*

[*]*National Research University Higher School of Economics, 101000 Moscow, Russia*

Submitted 18 June 2026
Resubmitted 18 June 2026
Accepted 18 June 2026

Here, we present the results of an investigation of how the pressure affects the splitting of the superfluid transition temperature in ^{3}He in anisotropic aerogel. It is well known that boundary conditions significantly influence the properties of superfluid phases in aerogel. When aerogel strands are coated with a ^{4}He layer in magnetic field, new phases, such as the polar, polar-distorted A (DA), polar-distorted B (DB), and β phases, become energetically favorable. In contrast, without this coating, the system tends to favor phases resembling the bulk A, B, and A_1 phases. Our earlier results showed a nonlinear dependence of the superfluid transition temperature splitting in pure ^{3}He, but the range of nonlinearity did not match the theoretical predictions based on magnetic scattering effects. To further investigate this discrepancy, we performed measurements of the splitting under varying pressures for both pure ^{3}He and with ^{4}He coverage of the aerogel strands.

DOI: 10.7868/S3034576626080074

Introduction. In nematic aerogel, where the strands are almost parallel to one another, in the case of ^{4}He-coated strands (specular boundary conditions) new superfluid phases of ^{3}He are realized – the polar and β (in magnetic field) phases [1, 2]. On the contrary, in the absence of ^{4}He (using pure ^{3}He), the strands are covered with solid paramagnetic ^{3}He layer making the scattering of quasiparticles diffuse and enabling a magnetic scattering channel, so that the A and A_1 (in magnetic field) phases are realized instead [3]. Our recent experiments with pure ^{3}He in nematic aerogel [4] revealed a discrepancy in the splitting of the superfluid transition temperature in magnetic field from a theoretical prediction regarding the range of fields where nonlinearity in the field dependence of the splitting should occur. It is expected that the solid ^{3}He coatings on the aerogel strands acting like paramagnetic impurities should suppress the splitting at the fields ≤ 20 kOe, while at higher fields the splitting recovers linearity as the solid ^{3}He magnetization saturates [5]. The upper (T_{ca1}) and lower (T_{ca2}) critical temperatures are given by:

$$T_{ca1,2} = T_{ca} \pm \left[\eta_{1,2} - C_{1,2}\frac{\tanh(\alpha H)}{\alpha H}\right] H, \qquad (1)$$

where $\eta_{1,2} = \eta^0_{1,2} \cdot T_{ca}/T_c \sim 1\,\mu$K/kOe [6] are the splitting parameters in the absence of spin exchange ($\eta^0_{1,2}$ are those for the bulk A_1 phase), $C_{1,2} \sim 1\,\mu$K/kOe are the spin-exchange parameters, T_c and T_{ca} are zero-field superfluid transition temperatures of bulk ^{3}He and in ^{3}He in aerogel respectively. The field scaling factor $\alpha = \gamma\hbar/(2k_BT_{ca}) = \alpha_0 \cdot T_c/T_{ca}$ contains the gyromagnetic ratio γ of ^{3}He nuclei and Boltzmann constant k_B. Here, α_0 corresponds to the case of zero suppression of a superfluid transition temperature.

In the present work we carry out a systematic investigation of a pressure effect on the splitting in pure ^{3}He (without ^{4}He coverage), as well as in the case of ^{4}He preplating to neutralize the magnetic scattering mechanism in the ^{3}He quasiparticle scattering processes.

Methods. The measurements were done using aerogel vibrating wire (VW) resonator oscillated in the direction parallel to the strands, utilizing a nuclear demagnetization cryostat to achieve temperatures ~ 1 mK and a quartz tuning fork for thermometry. The sample was provided by Metallurg Engineering Ltd, having a bulk density of approximately 3.1 g/cm^3, a porosity of 95.2 %, and a final density of 150 mg/cm^3. The aerogel strands had a diameter of ≤ 14 nm, and the characteristic distance between strands was 60 nm. The sample had a shape of cuboid with dimensions of approximately 2×3 mm transverse to the strands and 2.6 mm along the strands. The sample was glued to a 240 μm NbTi wire using Stycast-1266 epoxy. The wire was bent into an arch shape with a total height of 10 mm and leg separation of 4 mm.

1)e-mail: soldatov_a@kapitza.ras.ru

In pure ^{3}He, measurements were performed in magnetic fields $H = 5$–31 kOe and at pressure of 7.1 bar. For the case of ^{4}He coverage, measurements were conducted in magnetic fields $H = 1$–11 kOe at pressures of 7.1 and 19.4 bar. During the experiments, an alternating current was applied to the wire, with amplitude I_0 varying from 0.85 to 2 mA and from 0.4 to 4.4 mA depending on H for the cases of pure ^{3}He and ^{4}He coverage respectively. The current amplitude was set to ensure field-independent oscillation amplitude ($HI_0 = \text{const}$). In liquid ^{3}He the wire maximum velocity in the used temperature range was ≤ 0.2 mm/s not overheating ^{3}He in and outside the aerogel sample. In the magnetic field produced by the main solenoid, the wire oscillated perpendicular to this field, generating an electromotive force (EMF). EMF signal was amplified by a step-up transformer 1:30 and measured using a lock-in amplifier. By slowly warming up the system and scanning the frequency, resonance curves were recorded and approximated by Lorentzian fits. These fits were used to construct the temperature dependence of the resonance parameters, allowing determination of the superfluid transition temperatures.

Results. Figure 1 presents T_{ca1} in nematic aerogel without ^{4}He coverage. In our previous work at 15.4 bar [4] we have found that T_{ca1} exhibits ≈ 6 times smaller region of nonlinearity (around 5 kOe) than expected, determined by α. At higher fields it saturates and becomes linear, with the same slope as in the bulk phase with the same zero-field critical temperature. This much narrower region of nonlinearity contradicts the theory [5], but can be explained by the other effect of magnetic correlations [7]. As for 7.1 bar, we obtain T_{ca1} with a rather worse accuracy and the saturation is not obvious in the used fields. The fit having correct α_0 seems to be acceptable, but not sufficient enough to tell that the spin-polarized impurity model works here for sure.

Measurements of the splitting with ^{4}He coverage allowed to obtain the value of $\frac{-\beta_{15}}{\beta_{12345}}$ for all pressures. It turned out to be 3.5 at 7.1 bar, noticeably larger than expected for bulk ^{3}He and ^{3}He in silica aerogel, while at higher pressures being within the acceptable range.

Conclusions. In this work, we investigated the splitting of the superfluid transition temperature in ^{3}He in nematic aerogel under varying pressures. Without ^{4}He coverage, the observed nonlinearity in T_{ca1} spanned across a wider range of fields at lower pressure, while at higher pressure a clear transition to linear regime was observed. At higher pressure, the region of nonlinearity is significantly narrower than predicted by theory. We attribute this discrepancy to correlations in the magnetization of impurities. With ^{4}He coverage, the splitting of the transition temperature exhibited a more symmetric field dependence, with the ratio of slopes for the upper and lower transitions aligning more closely with theoretical predictions for bulk ^{3}He.

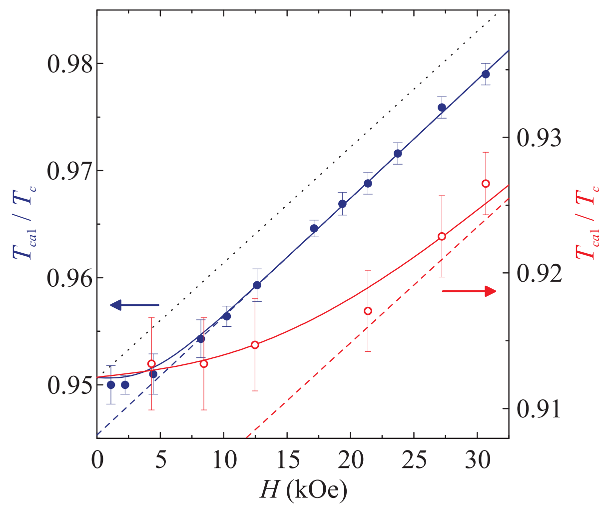

Fig. 1. (Color online) The upper superfluid transition temperature in nematic aerogel without ^{4}He coverage at pressures of 15.4 bar (left scale, filled symbols, $T_{ca} \approx 0.951T_c$) and 7.1 bar (right scale, open symbols, $T_{ca} \approx 0.912T_c$). The dotted line represents the bulk upper phase transition for both pressures scaled to their corresponding T_{ca}/T_c (coincide due to the chosen axis scaling) [6]. For both pressures, the solid lines are the best fit of our data with Eq. (1), where η_1^0 was set to the value expected for bulk A_1 phase [6]. For 7.1 bar $\alpha_0 \approx 0.047\,\text{kOe}^{-1}$ was fixed according to the theory as well, while for 15.4 bar α_0 was a fitting parameter resulting in $\alpha \approx 0.215\,\text{kOe}^{-1}$ which is basically 6 times higher than its expected value $\alpha \approx 0.039\,\text{kOe}^{-1}$. The dashed lines are asymptotes of the high-field data. Data for 15.4 bar are from [4]

Funding. This work was supported by ongoing institutional funding in P. L. Kapitza Institute for Physical Problems of Russian Academy of Sciences. No additional grants to carry out or direct this particular research were obtained.

Conflict of interest. The authors of this work declare that they have no conflicts of interest.

1. V. V. Dmitriev, A. A. Senin, A. A. Soldatov, and A. N. Yudin, "Polar Phase of Superfluid ^{3}He in Anisotropic Aerogel", Phys. Rev. Lett. **115**, 165304 (2015).
2. V. V. Dmitriev, M. S. Kutuzov, A. A. Soldatov, and A. N. Yudin, "Superfluid β phase of ^{3}He", Phys. Rev. Lett. **127**, 265301 (2021).
3. V. V. Dmitriev, A. A. Soldatov, and A. N. Yudin, "Effect of Magnetic Boundary Conditions on Superfluid ^{3}He in Nematic Aerogel", Phys. Rev. Lett. **120**, 075301 (2018).

4. V. V. Dmitriev, M. S. Kutuzov, D. V. Petrova, A. A. Soldatov, and A. N. Yudin, "A_1-A_2 Splitting in Pure ^{3}He in Nematic Aerogel", JETP Lett. **122**, 444 (2025).
5. G. A. Baramidze and G. A. Kharadze, "Superfluid ^{3}He in Presence of Spin-Polarized Scattering Centers", J. Low Temp. Phys. **135**, 399 (2004).
6. U. E. Israelsson, B. C. Crooker, H. M. Bozler, and C. M. Gould, "Phase Diagram of Superfluid ^{3}He-A_1", Phys. Rev. Lett. **53**, 1943 (1984).
7. V. S. Mikheeva and E. V. Surovtsev, "Effect of Spatial Correlations of the Impurity Magnetization on the Transition Temperature to the A_1-Phase of Superfluid ^{3}He", JETP Lett. **121**, 545 (2025).