Majorana Fermions: Direct Measurements in superfluid ^{3}He.

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The Majorana fermions, which acts as its own antiparticle, was suggested by Majorana in 1937. While no stable particle with Majorana properties has not yet been observed, Majorana quasiparticles (QPs) was suggested at the boundaries of topological insulators, like superfluid ^{3}He-B. Here we report the direct observation of Majorana QPs by precise measurements of the superfluid ^{3}He-B heat capacity. We have succeed to separate the temperature dependence of the bulk Bogolyubov fermions and the surface Majorana fermions heat capacity. The Bogolyubov QPs in bulk ^{3}He-B have a gap and consequently its heat capacity drops down exponentially with cooling. The Majorana QPs behave as a two dimensional gas on the surface of the cell with ^{3}He-B. Majorana QPs have a zero gap, but they have a kinetic energy. Owing to this energy the Majorana QPs have a heat capacity, which drops down with cooling by power law. In our experiments we have found the deviation of exponential law of Bogolyubov QPs heat capacity, which corresponds well to an additional heat capacity due to zero gaped Majorana particles. The very good agreement with a theoretical prediction supports our claim of a direct observation of zero gaped Majorana particles.

For to measure the heat capacity of the box with ^{3}He-B we have used two Vibrating Weirs of micron thickness in the shape of semi-loop. The damping of the mechanical resonance of these loops determines by the density of Bogolyubov QPs. Apparently the VWR is the best ^{3}He

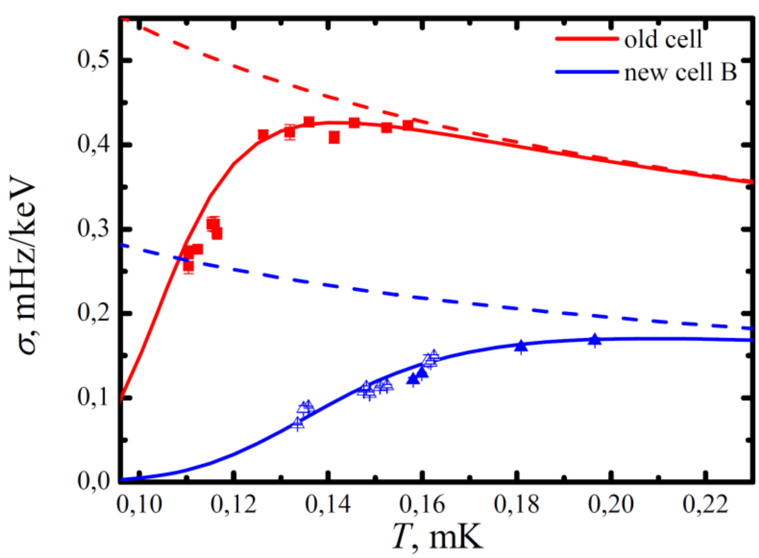

Fig.1. The instant changes of VWR broadening on the heating pulse at different temperatures. Red points – the old cell with surface to volume ration 87 (1/cm). Blue points – the new cell with the ration of 2000 (1/cm). The dashed line corresponds to Bogolyubov QPs. Solid line – the additional Majorana heat capacity taken into account.

thermometer for the region of extremely low temperatures We have force one of VWR to move with a supercritical velocity for a short time. The VWR creates directly the QPs. The thermal response in the units of thermometer VWR broadening is shown in Fig. 1. (We have used the 4 μm wire for the old cell and 10 μm wire for the new one.) We can see that the experimental points fit well to the theoretical prediction without fitting parameters!

In Fig. 2. we shows the heat capacity of two cells with ^{3}He-B at zero bar as a function of temperature, recalculated from the results of Fig.1.

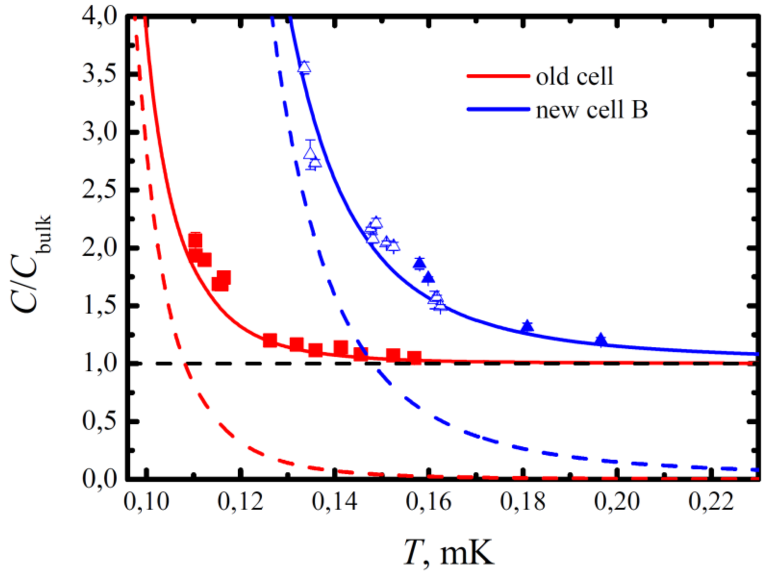

Fig.1. The heat capacity of the cells with ^{3}He-B normalized on the Bogolyubov QPs heat capacity. Red dashed line – the calculated heat capacity of Magorana in the old cell and blue dashed line – the heat capacity of Majorana in the cell with surface enlarged on 22. Solid lines – the total heat capacity in the cells.

In conclusion we can say that the additional heat capacity corresponds well to estimated Majorana heat capacity. Its changes in according with the surface of the cell and proportional to a T^2 low, predicted for Majorana. Furthermore, we have not used fitting parameters. The Bogolyubov QPs heat capacity is determines in the region of high temperatures in the old cell. The surface determines by geometry of the cells. We have used the rifeness of the walls equal to 10, which corresponds well to a mechanical data of cooper. Furthermore, the other thermal reservoirs, like phonons and magnons can give the additional heat capacity on 2 -3 orders of magnitude lower. The possible solid layer of ^{3}He atoms should not depend as T^2 with cooling.

[1] . Yu. M. Bunkov, "Direct Observation of a Majorana Quasiparticle Heat Capacity in 3He" J. Low Temp. Phys., 175, 385-394 (2014);
[2] Yu. M. Bunkov, R. R. Gazizulin arXive:1504.01711 (2015)