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Second sound in a collisionally hydrodynamic Bose gas[1]

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In 1995 Bose-Einstein condensation (BEC) in dilute Bose gases has been realized experimentally for the first time. Although the first condensates were created with a few million atoms or less, it has been speculated at that time that soon the number of atoms would increase considerably such that the sample becomes hydrodynamic. This would allow to enter the regime of the Landau two-fluid model for dilute Bose gases, where experiments in liquid helium below the λ-point have been very successful. Since that time a few experiments have been carried out where the sample was close to hydrodynamic, although most of the experiment using dilute Bose gases have been in the collisionless regime. We have been carrying out experiments, where for the first time the sample is fully hydrodynamic in the axial direction. We have displaced the condensate with respect to the thermal cloud and subsequently released the condensate, such that it moves through the thermal cloud [1]. Contrary to the superfluid properties of the condensate we observe damping of the out-of-phase motion between condensate and thermal cloud. In another experiment we locally heat the sample of condensate and thermal cloud and observe the equilibration of the sample to a homogeneous temperature extending our work above T_c [2]. We observe two standing wave sound modes, where the mode in the condensate (thermal cloud) is associated with second (first) sound. In a final experiment we directly induce a wave by locally decreasing the density in the condensate and measure its propagation speed [3]. The speed of sound, which is 5-10% smaller compared to the Bogoliubov speed of sound, is compared to the speed of second sound in the Landau two-fluid hydrodynamics model. We observe excellent agreement between the model and experiment in a large range of temperatures. These experiments open the field of quantum hydrodynamics for dilute Bose gases and broadens our knowledge on second sound and superfluidity.

[1] R. Meppelink et al., *Damping of superfluid flow by a thermal cloud*, Phys. Rev. Lett. (accepted).
[2] R. Meppelink et al., *Enhanced Heat Flow in the Hydrodynamic Collisionless Regime*, Phys. Rev. Lett. 1030953012009.
[3] R. Meppelink et al., *Sound propagation in a Bose-Einstein condensate at finite temperatures*, Phys. Rev. A 80 043605 2009.

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