

Bose-Einstein Condensation in Solid Helium

S.O. Diallo, R. T. Azuah, O.Kirichek, J. W. Taylor, and H.R. Glyde

Superconductivity (superflow of charged electrons), superflow in liquid helium and in dilute gases were first reported in 1911, 1938, and 1995, respectively. Each discovery lead to a Nobel prize. In these 3D fluids, superflow arises from Bose-Einstein condensation (BEC), the macroscopic occupation of a single quantum state at low temperature.

In 2004, remarkably, a superfluid component in solid helium was reported [1](see figure opposite, from Ref. [1]). This is quite unexpected since in solids the atoms are localized around lattice points. The apparent superfluid fraction, ρ_S , has been verified in several independent measurements and superflow is believed to be via defects; for example, mobile vacancies, or in dislocations, in grain boundaries, in amorphous regions and or along surfaces -- and arises from BEC as in fluids [2,3]. The largest ρ_S values are observed [4] in solids that have a large surface to volume (S/V) ratio, e.g. $\rho_S \sim 20\%$ for $S/V \sim 100\text{ cm}^{-1}$.

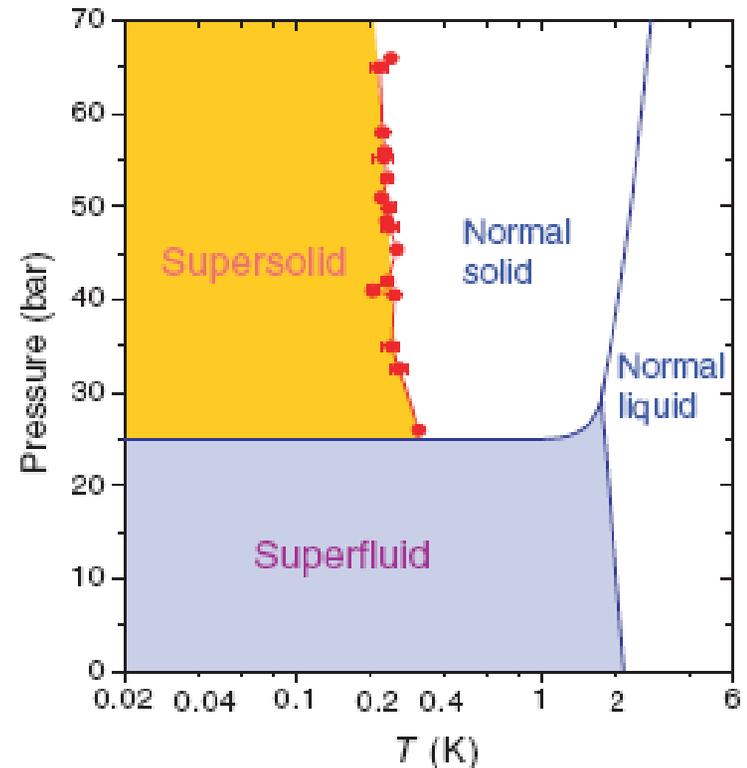


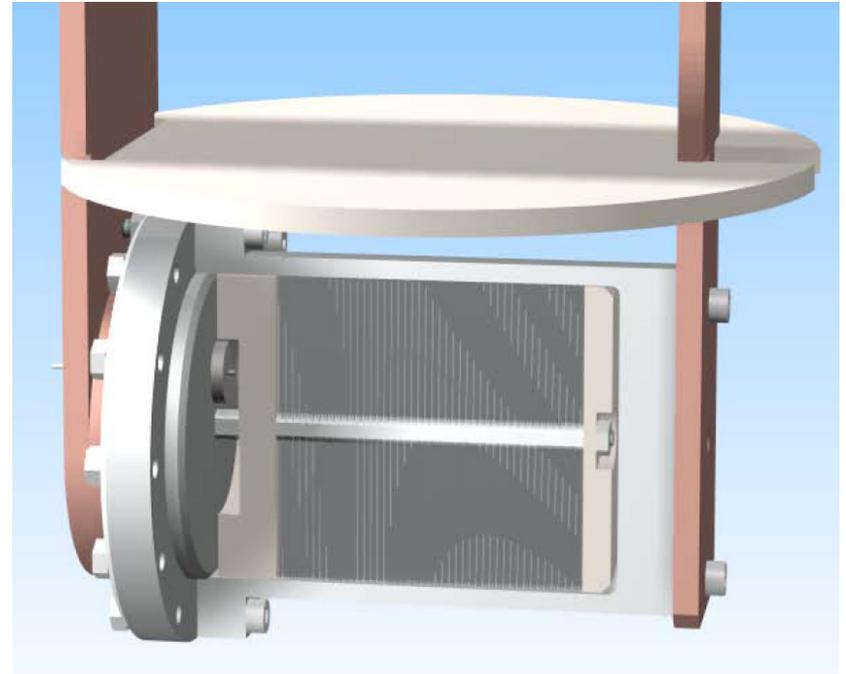
Fig. 4. Phase diagram of liquid and solid helium.

[1] E. Kim and M.H.W. Chan. Science, **305**:1941 (2004); Nature, **427**:225, (2004). [2] H. R. Glyde, Nature, **444**: 695 (2006) [3] S. Balibar and F. Caupin, J. Phys.: Condens. Matter **20**: 173201 (2008). [4] A. S. C. Rittner, and J. D. Reppy, Phys. Rev. Lett., 98:175302, (2007); **101**, 155301 (2008)

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Direct observation of BEC, i.e. a macroscopic fraction, n_0 , condensed in the zero momentum state, as well as the apparent ρ_S , would be convincing evidence of superflow in solid helium. The BEC n_0 , is uniquely determined using inelastic neutron scattering. In our first measurement [5] on a bulk solid, we found n_0 to be zero within precision, less than 1 %. With new cryogenics, improved instrument precision and using a sample in which the solid has a large surface to volume ratio, $S/V = 40 \text{ cm}^{-1}$ (see sample cell opposite containing 95 sheets of aluminum), we again find n_0 is zero within approximately 0.3 % in new data [6] now being analysed. To date measurement of BEC fails to confirm superflow.



In the future, in this rapidly developing field, we will improve these measurements further and investigate solid helium confined in the porous media MCM41 where S/V is extremely large. We have recently observed [7] BEC in liquid helium films in MCM-41.

- [5] S. O. Diallo et al., Phys. Rev Lett. **98**: 205301 (2007). [6] Diallo et al., Phys. Rev Lett.:(in preparation) (2009).
[7] S. O. Diallo et al., Phys. Rev. **B78**: 024512 (2008)..