On supersolid fraction

Yongle Yu

State Key Laboratory of Magnetic Resonance and Atomic and Molecular Physics,
Wuhan Institute of Physics and Mathematics, CAS, Wuhan 430071, P. R. China

We present an explanation of why the observed supersolid fractions of helium solids are rather far below unity. One might observe large supersolid fraction of neon systems immersing in liquid $^4$He. A system of bosonic ions in a ring trap could display a supersolid fraction close to unity.

PACS numbers: 67.80.-s

A supersolidic phase of matter is characterized by non-classical rotational inertia (NCRI) of solid $^4$He $[1,2,3]$. The observed NCRI fractions are rather far below unity and show dependence on the crystal perfection. The largest NCRI fraction is around 20 percents with a rapid freezing solid $^4$He $[3]$. These seem to suggest that supersolidity is related to disorder in solid. For the following considerations on superfluidity and on crystals, however, the observation of rather small NCRI fractions could be explained and the unclear disorder-related mechanism of supersolidity might be unnecessary. Superfluidity means that a system can decouple from the motion of its environment. A superfluidic crystal is frictionless given that temperature and velocity are low enough. However, having a rather fixed shape and regular facets, a superfluidic crystal responds to a normal force and moves (see Fig. 1). In typical supersolid experiments with solid $^4$He confined in an annual region, the walls contacting the solid are made cylindrical. However, the walls, which are solid themselves, microscopically can’t have a perfect cylindrical surface. Therefore, when the walls rotate, the spatial place (position) taken by the walls don’t remain the same, and the walls exert some normal force on part of solid $^4$He. The part of the solid which moves together with walls behaves like normal solid, although it might be supersolid.

The above considerations could also explain that the observed supersolid fraction decreases with annealing $[3]$. The smaller grains of crystal in the solid are, the less observed supersolid fraction decreases with annealing $[3]$. These seem to suggest that supersolidity is related to disorder in solid.

Superfluidity could be also realized in another system: a number of identical bosonic ions confined in a ring trap. The crystalline phase of ions in a trap has long being observed $[3]$. When identical Bose ions rotate in a ring, the system could demonstrate a frictionless motion with a supersolid fraction close to unity near zero temperature.

We recently discuss the possibility that solid $^{20}$Ne or solid $^{22}$Ne, having similar quantum character to that of solid $^4$He, could possess a supersolid phase $[4]$. It might be possible that one changes the experimental setup a little bit and observes rather large supersolid fraction in neon systems. One could fill an annual region with a mixture of liquid $^3$He and small grains of neon crystals. The neon crystals could then mostly response to the motion of liquid $^3$He and largely decouple from the motion of the walls. The liquid $^3$He shall be in the normal phase. The transition temperature of liquid $^3$He under ambient pressure is around 1 mK, which is likely lower than transition temperature of possible supersolidic neon.

Supersolidity could be also realized in another system: number of identical bosonic ions confined in a ring trap. The crystalline phase of ions in a trap has long being observed $[3]$. When identical Bose ions rotate in a ring, the system could demonstrate a frictionless motion with a supersolid fraction close to unity near zero temperature.

FIG. 1: A supersolid crystal (square) is frictionless (left). But it moves under a normal force (right).

[1] E. Kim and M. H. W. Chan, Nature 427, 225 (2004); Science 305, 1941 (2004); Phys. Rev. Lett. 97, 115302 (2006); Low Temp. Phys. 138 (3-4), 859 (2005); A. C. Clark, J. T. West, and M. H. W. Chan, Phys. Rev. Lett. 99, 135302 (2007); X. Lin, A. Clark, and M. H. W. Chan, Nature 449, 1025 (2007). J. T. West, X. Lin, Z. G. Cheng, and M. H. Chan, Phys. Rev. Lett. 102, 185302 (2009).

[2] A. Penzev, Y. Yasuta, and M. Kubota, J. Low Temp. Phys. 148, 667 (2007); M. Kondo, S. Takada, Y. Shibayama, and K. Shirahama, ibid. 148, 695 (2007); Y. Aoki, J. C. Graves, and H. Kojima, Phys. Rev. Lett. 99, 015301 (2007); A. S. C. Rittner and J. D. Reppy, Phys. Rev. Lett. 97, 165301 (2006); ibid. 101, 155301 (2008).

[3] A. S. C. Rittner and J. D. Reppy, Phys. Rev. Lett. 98, 175302 (2007).

[4] Y. Yu, cond-mat/0609712.

[5] see, e.g., I. Waki, S. Kassner, G. Birkl, and H. Walther, Phys. Rev. Lett. 68, 2007 (1992); F. Diedrich, E. Peik, J. M. Chen, W. quint, and H. Walther, ibid. 59, 2931 (1987); D. J. Wineland, J. C. Bergquist, Wayne M. Itano, J. J. Bollinger, and C. H. Manney, ibid. 59, 2935 (1987); T. Schätz, U. Schramm, and D. Habs, Nature 412, 717 (2001).