Superfluid to Mott insulator quantum phase transition in permanent magnetic lattices

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We study quantum degenerate Bose gases at finite temperatures in optical [1] and magnetic [2] lattices and in particular the superfluid to Mott insulator quantum phase transition. We investigate ultracold atoms in a grand canonical ensemble [3] and use the Bose-Hubbard model [4] which can describe the dynamics of ultracold atoms in periodic potentials such as optical and magnetic lattices. Based on a truncated number-state basis, in 1D, 2D and 3D, the Mott insulator lobes start melting at temperature $T_0 = 0.06\,U$, where U is the on-site interaction energy. Figure 1(a) shows the local compressibility

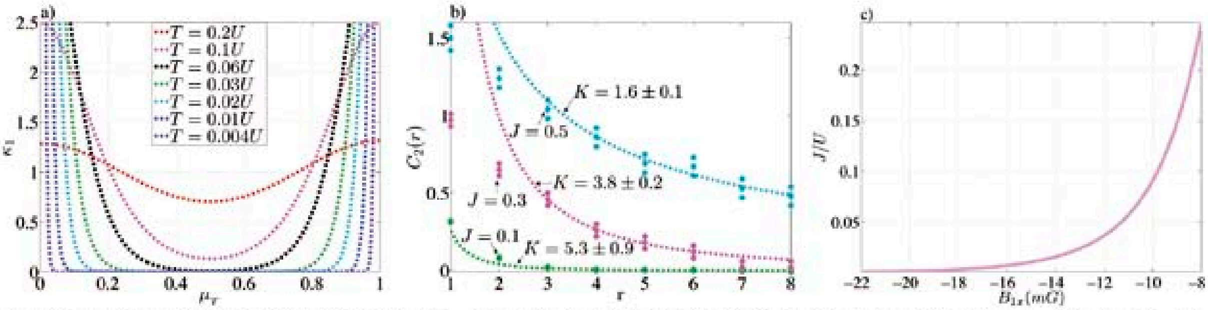

Figure 1: (a) The local compressibility κ_1, at each site, versus the target chemical potential, μ_T, for $J = 0$. (b) Atom-atom correlations, $C_2(r)$, as a function of r, the site number, for M=11, $\mu_T = 0.5$, $T = 0.5\,U$ and values of $J = 0.1, 0.3$ and 0.5. Diamonds and circles around them show the simulation results and their sampling error, respectively. Dashed lines are fits to the function $r^{-K/2}$, for $r \gg 1$, where K is the Luttinger parameter. (c) J/U versus B_{1x}, the x component of the bias magnetic field, in a 2D permanent magnetic lattice shown in figure 2 of reference [2], for $t_1/a = 0.3$, $t_2/a = 0.1$, $s/a = 0.5$ and $a = 1\ \mu m$ where t_1, t_2, s and a are geometrical parameters defined in [2] and a is the period of the lattice.

$\kappa_1 = \partial \langle \hat{n}_1 \rangle / \partial \mu_T$, at each lattice site, versus μ_T, where $\hat{n}_1$ and μ_T are the number operator at each lattice site and the target chemical potential at the temperature T, respectively, for $J = 0$ at different temperatures, and J is the hopping matrix element. At zero temperature, the Mott insulator phase is defined by $\kappa_1 = 0$. According to the gauge P representation, in a 1D system all the measures of the coherence between lattice sites and their relative values with respect to the average number of atoms in the central site increase when either the temperature is reduced or the hopping matrix element is increased. According to figure 1(b), at the constant temperature $T = 0.5\,U$, the atom-atom correlations $C_2(r)$, which are measures of the coherence between sites, increase with increasing J. Moreover, as J is increased the Luttinger parameter K decreases. Figure 1(c), based on the harmonic oscillator wave function approximation, shows that the critical value of the superfluid to Mott insulator quantum phase transition, $(J/U)_c = 0.043$ [5], is accessible in a 2D permanent magnetic lattice [2].

References

[1] D. Jaksch, C. Bruder, J.I. Cirac, C.W. Gardiner, and P. Zoller, Phys. Rev. Lett. **81**, 3108 (1998).

[2] S. Ghanbari, T.D. Kieu, A. Sidorov and P. Hannaford, J. Phys. B **39**, 847 (2006).

[3] P.D. Drummond, P. Deuar, and K.V. Kheruntsyan, Phys. Rev. Lett. **92**, 040405 (2004).

[4] M.P.A. Fisher, P.B. Weichman, G. Grinstein and D.S. Fisher, Phys. Rev. B **40**, 546 (1989).

[5] K. Sheshadri, H.R. Krishnamurthy, R. Pandit and T.V. Ramakrishnan, Europhys. Lett. **22**, 257 (1993).