# Gutzwiller study for phase diagram of extended Hubbard models with fixed boson densities

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We studied the phase diagram of extended Bose–Hubbard models with nearest-neighbor interaction on bipartite lattices in a canonical ensemble by using the Gutzwiller variational wave function and the linear programming method under the condition of fixed boson densities. Contrary to the hard-core model, the soft-core model at half filling has a possible SS phase between the solid and SF phases and all phase transitions are continuous. We also found that the phase diagram of the soft-core model strongly depends on its transfer integral $t$. For small $t$, the shape of the SF region is similar to that of the hard-core model with particle-hole symmetry and the SS phase does not appear because of the phase separation above half filling. In contrast, for large $t$, the SS phase appears even above half filling. The phase diagram becomes simplified for large $t$, where there is only a continuous SF–SS phase transition and the critical value of $t$ at the phase boundary is a smooth decreasing function of boson density $N$.
Finally, we also found that the density difference between nearest-neighbor sites $\delta n$, which shows the density wave order of the SS phase, strongly depends on the boson density $N$. In particular, for small $t$, the difference $\delta n$ is a discontinuous function of the nearest-neighbor interaction $V$ and is larger for smaller (larger) $N$ for small (large) $V$.