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Phase coherence, visibility, and the signatures of superfluid-Mott and metal-Mott insulator transitions on optical lattices

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Experiments are revealing, with increasing precision, details of the Mott insulating (MI) and superfluid (SF) phases of atomic condensates confined on optical lattices. Recently, details of the transition between the MI and the SF phases, as the lattice potential is changed, were examined by studying the visibility and phase coherence of the condensate. Reproducible kinks were observed in the visibility as the lattice potential was made deeper and the system moved into the MI phase. These kinks were interpreted as being due to the formation of the Mott region. We shall first review briefly the properties of the various phases of this system and how it makes the transition from SF to MI. Then we present a detailed Quantum Monte Carlo study of the visibility and other physical quantities as Mott domains begin to form. We show that as the lattice potential gets deeper and Mott domains become well established, the evolution of the system stalls: the density profile stops evolving for a substantial range of values of the lattice potential. As a consequence, the evolution of several other quantities also stalls and the visibility kink is produced. We offer an explanation of this behavior. We then extend our study to the formation of Mott domains in fermionic atoms on confined one-dimensional optical lattices. We find a new property of the metal–Mott insulator transition in a trap. The sum of kinetic and interaction energies exhibits minima when Mott domains appear in the system. In addition, we examine the derivatives of the kinetic and interaction energies, and of their sum, which display clear signatures of the Mott transition. We discuss the relevance of these findings to time of flight experiments that could allow the detection of the metal–Mott-insulator transition in confined fermions on optical lattices.