Disorder-Induced Localization in a Bose-Einstein Condensate

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Random disorder is known to play an important role in the electrical properties of conductors and superconductors. In those materials, disorder may be caused by crystal defects, impurities, or anything else that changes the landscape of how electrons move in a material. If the disorder is sufficiently strong to localize the electrons the material undergoes a transition to an insulating state, as has been observed in thin-film and granular superconductors. A complete understanding of the transition and the nature of the insulating state remain elusive due to the limitations imposed by the complexity of actual materials. Atomic Bose-Einstein condensates (BECs) afford the opportunity to explore the role of disorder in superfluids where the physical parameters are well characterized, and moreover, can be varied. The interplay of disorder and interactions is of particular interest, because weakly interacting disordered systems can undergo a quantum phase transition to the Anderson localized state.

We have studied the transport and phase coherence properties of a ^{7}Li BEC in the presence of disorder produced by optical speckle[1]. At moderate disorder strengths, V_d, we observe inhibited transport and damping of dipole oscillations. Contrary to previous expectations, in-situ density measurements reveal only small density modulations in this regime. Time-of-flight images exhibit random but reproducible interference. Only at much higher V_d does the condensate fragment into many quasi-independent pockets, which is accompanied by a reduction of interference contrast. These measurements show that while transport of the condensate is inhibited at moderate V_d, the condensate remains connected and phase coherent.

Anderson localization, recently observed in atomic BECs[2,3], arises from single particle interference which requires that atomic interactions be sufficiently weak that the condensate healing length is larger than the disorder length scale. ^{7}Li is an interesting atom for these studies because the scattering length, a, can be readily varied via a Feshbach resonance. Of particular interest is the ability to tune a close to and through zero[4], providing a systematic way of varying the healing length. We are using this zero-crossing to investigate the role of weak interactions, both repulsive and attractive, in the presence of disorder.

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