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Critical Collisional Opacity in a Bose-Einstein Condensate

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In a Bose-Einstein condensate due to the very low temperature the s-wave scattering length can be used as a measure for the strength of the atom-atom interaction. Under typical experimental conditions this interaction is weak and, hence, can be treated in terms of a mean field. However, when the scattering length is large or the density is high, the mean field approximation breaks down. In this collisional (hydrodynamic) regime, effects of the interactions such as quantum depletion 1 or shifts in the frequencies of the elementary excitations become large. It is therefore of great interest to study condensates close to or in the collisional regime. It has been demonstrated in recent experiments that the scattering length and thus the interactions among the atoms can be tuned by means of a Feshbach resonance.5,6 In the vicinity of Feshbach resonances, however, the increase of the cross-section for elastic collisions is accompanied by a dramatic increase of particle losses.

In this paper we report on the observation of anomalous losses from a 87Rb condensate with a high column density in the absence of inelastic scattering resonances. We identify a loss process that limits the achievable column density of ultracold trapped gases in the off-resonant scattering regime as well as in the vicinity of a Feshbach resonance. It is based on collisional avalanches that are triggered by inelastic collisions between trapped atoms or sometimes even by background gas collisions. In the avalanche a considerable part of the kinetic energy of the particles are gained in the inelastic collision is distributed among the trapped atoms by secondary elastic collisions. In our experiment this results in an 8-fold increase of the initial loss rate with respect to the prediction accounting for known loss mechanisms. We present a model accounting for avalanche-size-like losses which is in good agreement with the observed anomalous decay of our condensate. Our analysis reveals that the collisional opacity of an ultra-cold and dense gas exhibits a critical value. When the critical opacity is exceeded, losses induced by inelastic collisions are substantially enhanced.

References


Direct observation of growth and collapse of a Bose-Einstein condensate with attractive interactions

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Quantum theory predicts that Bose-Einstein condensation (BEC) of a spatially homogeneous gas with attractive interactions is precluded by a conventional phase transition into either a liquid or solid. 1,2 When confined to a trap, however, such a condensate can form 3 provided that its occupation number \( N_0 \) does not exceed a limiting value. 3,4 The stability limit is determined by a balance between self-attraction and a repulsion arising from position-momentum uncertainty under conditions of spatial confinement. Near the stability limit, self-attraction can overwhelm the repulsion, causing the condensate to collapse. 3,4 Growth of the condensate, therefore, is punctuated by intermittent collapses, 5,6 which are triggered either by macroscopic quantum tunneling or thermal fluctuation.

Direct observation of growth and collapse has been hampered by the stochastic nature of the collapse initiation mechanisms. However, we previously measured the spread in \( N_0 \) values at selected times following a fast quench of a gas of Li atoms to be distributed between small numbers, \( N_0 = 100 \), and the maximum number of ~ 1250 atoms, in agreement with the growth and collapse model. 7 The process of making reliable measurements of such small values of \( N_0 \) destroys the condensate, preventing an observation of its dynamics in real time. In the present work, direct observation of the dynamics is made possible by dumping the condensate at a specified time, thereby synchronizing the growth and collapse cycles upon repetition of the experiment. To dump the condensate, a light pulse consisting of two co-propagating laser beams whose frequency difference is tuned to resonance between the collisional state of two free atoms and a vibrational level of the diatomic molecule \( \text{Li}_2 \), is applied to the atom cloud as shown in Fig. 1. When the laser difference frequency is tuned properly, the condensate can be selectively removed, since the observed two-photon linewidth of ~ 0.050 kHz is much less than the ~ 5 kHz thermal energy spread of the trapped atoms.

Following the light pulse, the gas is allowed to freely evolve for a certain time, at which point a destructive measurement of \( N_0 \) is made. Figure 2 shows the dynamical evolution of the condensate following a light pulse whose duration is adjusted to reduce \( N_0 \) to an initial value of ~ 100 atoms. \( N_0 \) increases immediately following the light pulse as the condensate is fed via collisions between noncondensed thermal atoms, reaching a maximum value consistent with the expected upper limit of 1250 atoms. A collapse is clearly indicated by the