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Studies of atomic spin-orbit coupling synthesized with gradient magnetic fields

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Synopsis: Atomic spin orbit coupling (SOC) can be synthesized with modulating gradient magnetic field (GMF). This is confirmed through studying collective dipole oscillations for a spin-1 atomic condensate in a harmonic trap after abruptly turning on SOC, and studying adiabatically adjusted equilibrium states when SOC strength is slowly ramped up. Further measurements reveal that SOC can be enhanced when the GMF modulation frequency approaches trapping frequency.

We report the observation of tunable spin-orbit coupling (SOC) in spin-1 atoms synthesized with periodically driven gradient magnetic fields (GMF) [1]. SOC represents an important type of synthetic gauge fields actively pursued in cold atom systems. Recently, a new scheme based on pulsed or periodically modulating GMF is proposed to synthesize one dimensional (1D) SOC in a spin-1 atomic Bose-Einstein condensate (BEC) [2,3]. Different from all previous experiments which demonstrate synthesized SOC with Raman coupling lasers, this new scheme employs only magnetic field, thus could avoid the heating from atomic spontaneous emission in the Raman scheme. The strength of SOC synthesized with GMF can be tuned simply through adjusting the impulse, or the time integrated area of GMF. This is confirmed based on the measurements of a) collective dipole oscillations of a BEC in a harmonic trap after abruptly turning on SOC, and b) its adiabatically adjusted equilibrium states when the strength of SOC is slowly ramped up.

The 1D SOC we synthesize is an equal weighted sum of the Rashba and Dresselhaus types. With SOC, the free atom dispersion from without SOC splits into multi sub-bands, with its original minimum centered at zero momentum shifted to M_F k_{so} for spin component M_F. When SOC is turned on abruptly, atoms experience spin dependent restoring forces which induce both position and momentum oscillations for M_F =1,-1 components (Fig. 1). If SOC is slowly ramped up, atoms at the minimum will follow the ramp and stay at the shifted minimum (Fig. 2).

Our observations are in excellent agreement with theoretical predictions for both cases. This study also uncovers theoretical understanding and experimental confirmation that the strength of SOC can be enhanced making use of motional resonance associated with atomic center of mass in a harmonic trap. In addition to providing extra tunability and flexibility for GMF based scheme, this new finding also sheds light on experimental efforts towards synthesizing two-dimensional (2D) atomic SOC.

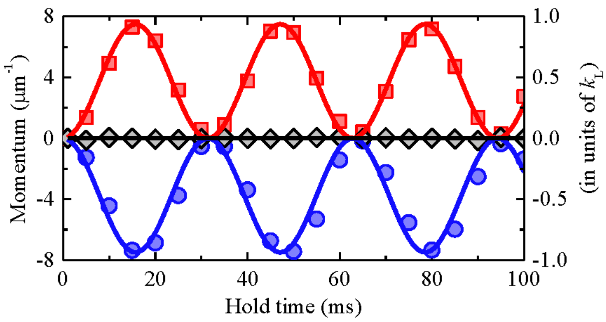

Figure 1. Measured momentum for the M_F=1, 0, -1 spin components respectively denoted by squares, diamonds, and disks as a function of hold time in a harmonic trap after abruptly turning on SOC.

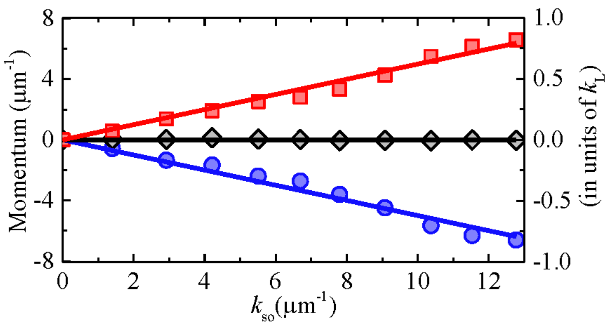

Figure 2. The same as in Fig. 1 but for the shifted minimum equilibrium momentums of the three spin components as a function of SOC strength k_{so}, after slowly ramping up SOC strength.

References

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