Magnetic Dipole-Dipole interactions in Spinor Bose-Einstein Condensates

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We discuss gaseous BECs with the magnetic dipole-dipole interactions by focusing on the spin degrees of freedom. Since the dipole-dipole interaction is long-range and anisotropic, it is expected to yield ground-state spin texture in a ferromagnetic BEC, as in the case of the domain structure in a solid-state ferromagnet. The unique feature of the spinor dipolar BEC which is absent from a solid-state ferromagnet is the spin-gauge symmetry which relates the spin texture to a mass current. Therefore, a substantial orbital angular momentum is expected to spontaneously emerge in a ground state of a spinor dipolar BEC.

We have numerically explored the ground state of a spin-1 ferromagnetic BEC and Fig. 1 (a) shows the results [1], in which R_{TF} is the Thomas-Fermi radius, ξ_{dd} is the dipole healing length, and ξ_{sp} is the spin healing length. We find three phases. In particular, in the phase which we refer to as chiral spin-vortex (CSV) phase, spontaneous circulation emerges accompanied by chiral symmetry breaking. Figure 1 (b) shows the orbital angular momentum of a spin-1 ^{87}Rb BEC along the dotted line in Fig.1 (a). In the CSV phase, the orbital angular momentum per particle is increased by up to $0.4\hbar$. The spin texture in CSV phase is similar to Mermin-Ho structure in the superfluid ^{3}He A-phase in which the boundary condition of the container induces mass current. In the case of an atomic BEC, the intrinsic dipolar interaction generates superfluid flow in the ground state.

We also present an experimental scheme to observe the extremely weak magnetic dipole-dipole interaction of alkali atoms [2].
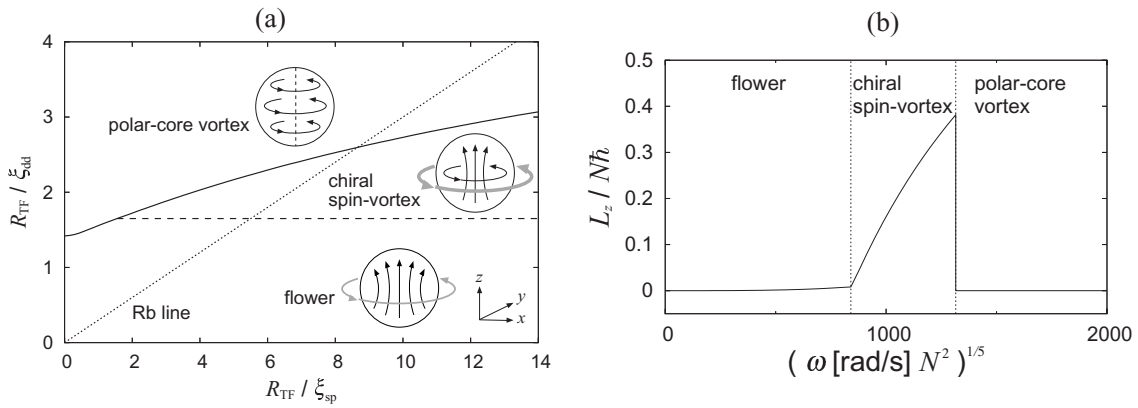

Fig. 1: (a) Phase diagram of a spin-1 ferromagnetic dipolar BEC. The schematic diagram shown in each region represents the spin configuration (black arrows) and mass flow (gray arrows). The spin-1 ^{87}Rb BEC traces the dotted line where $\xi_{\mathrm{sp}}/\xi_{\mathrm{dd}} = 0.30$. (b) Orbital angular momentum as a function of trap frequency ω and number of atoms N for a spin-1 ^{87}Rb BEC along the dotted line in Fig. 1(a).

[1] Y. Kawaguchi, H. Saito and M. Ueda, Phys. Rev. Lett. **97**, 130404 (2006).
[2] Y. Kawaguchi, H. Saito and M. Ueda, Phys. Rev. Lett. **98**, 110406 (2007).