Acoustic radiation from vortex–barrier interaction in atomic Bose–Einstein condensate

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Abstract
We examine the dynamics of a vortex dipole in the Bose–Einstein condensates of trapped dilute atomic gases at zero temperature in the presence of a Gaussian barrier potential. The density anisotropy induced by the barrier enhances the acoustic radiation from the vortex dipole. This is due to the deviation of the condensate density from the equipotential curves and variation in the curvature of the vortex dipole trajectory. Due to the acoustic radiation, the vortex dipole dissipates energy and spirals towards the edge of the condensate. As a result, we observe an increase in the vortex–antivortex annihilation events. To examine the effect of the Gaussian barrier, we estimate the correction to the Thomas–Fermi condensate density using the perturbation expansion method and the results are in very good agreement with the numerical results.

Keywords: vortex dipole, Bose–Einstein condensate, Thomas–Fermi approximation, GP-equation, acoustic radiation, vortex–antivortex annihilation

1. Introduction
The dynamics of topological defects, like vortices in nonlinear systems is the key to understanding important phenomena in chemical patterns, fluid dynamics, liquid crystals, superfluids etc [1–3]. In scalar Bose–Einstein condensates (BECs) [4–6], vortices carry integral angular momentum and serve as the obvious signature of superfluidity of these systems [7, 8]. The various experimental techniques which have been employed to generate vortices in BECs include manipulating the interconversion between the internal spin states of an isotope [9], stirring the BEC with a laser beam [10], rotating the BEC [11], phase imprinting [12–14] and merging of BECs [15]. Vortex dipoles, consisting of vortex–antivortex pairs, have also been experimentally realized in BECs by moving the condensate across a Gaussian obstacle potential [16]. In a vortex dipole, vortices of opposite circulation cancel each other’s angular momentum and thus carry only linear momentum. This is the cause of several fascinating phenomena such as leap frogging, snake instability [17], etc. Another important dynamical phenomenon is the vortex–antivortex annihilation, which is expected to occur when a vortex and antivortex approach each other. There is, however, a dearth of experimental signature. The introduction of a Gaussian barrier, examined in this work, ensures that the vortex–antivortex annihilation occurs by modifying the trajectories through acoustic radiation by the (anti)vortex.

On the theoretical front, among other important phenomena, the creation and dynamics of a vortex dipole in a BEC at zero temperature [18–20], lack of annihilation of vortex dipoles [21, 22], effect of an oscillating Gaussian potential [23] and the impact of the density inhomogeneity on the vortex motion [24] have been examined in previous works. The stability and dynamics of the clusters of vortices and antivortices in pancake-shaped BECs has also been studied [25]. It may also be mentioned here that in phase-separated binary condensates, coreless vortex dipoles can be formed by passing an obstacle across the condensate [26] or changing the nonlinearities associated with the system [27]. The dynamics of a vortex dipole across an interface of quasi-2D two-component BECs has also been examined in [28].