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Time arrow in superfluid vortex dynamics

Michikazu Kobayashi
[1] School of Environmental Science and Engineering, Kochi University of Technology
e-mail (speaker): michikazu.kobayashi@kochi-tech.ac.jp

Quantum fluid is one of intriguing physical systems that show quantum effect in macroscopic scales. Liquid helium[1] and ultracold atomic Bose-Einstein condensates[2] are well-known examples of quantum fluid that show superfluidity with inviscid hydrodynamic flow. Besides superfluidity, another important feature of quantum fluid is quantization of circulation, i.e., all rotational flows are carried by quantized vortices[3], the circulation around which is quantized by a fixed value. Quantized vortices play an important role in dynamics of quantum fluid such as vortex nucleation, breakdown of superfluidity, vortex crystallization in rotating container, phase transition between superfluid and normal fluid, and quantum turbulence.

One of well-known mathematical framework for dynamics of quantum fluid is the nonlinear Schrodinger equation that can naturally describe the dynamics of quantized vortices including nucleation, annihilation, and reconnection of them. In particular, vortex reconnection is important phenomenon for vortex dynamics[4]. In the reconnecting dynamics, two vortices approach to each other, become partially anti-parallel, and change their topology by the partial annihilation of them.

Because the nonlinear Schrodinger equation has the time-reversal symmetry, the reverse dynamics for one reconnetion event is possible by taking the time reversal of the nonlinear Schrodinger equation. Investigating reconnection dynamics in detail suggests, however, that whether reconnection occurs or not is strongly dependent on the initial condiguration of vortices and there exists the “direction” of reconnection dynamics.

To characterize the direction of reconnection dynamics, we propose phase twisting[5] along vortices and show its behavior in various dynamics such as a simple reconnection, quantum turbulence, and thermal equilibrium.

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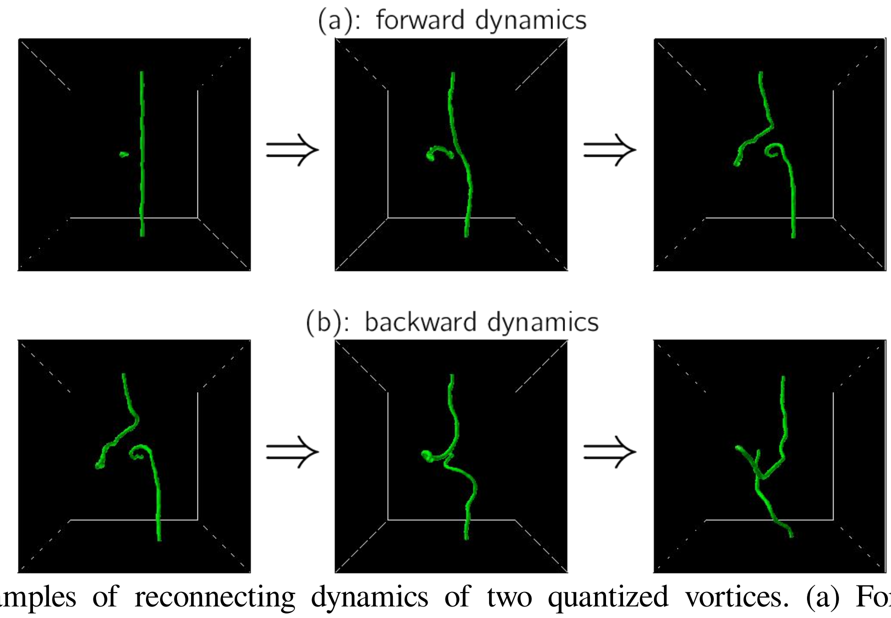

Figure 1. Examples of reconnecting dynamics of two quantized vortices. (a) Forward dynamics (reconnection occurs). (b) Backward dynamics (reconnection does not orrurs). The final state in panel (a) (right) is similar to the initial state in panel (b) (left), but they are not exactly the same.