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Controlling vortex motion and vortex kinetic friction

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Abstract

We summarize some recent results of vortex motion control and vortex kinetic friction. (1) We describe a device [J.E. Villegas, S. Savel'ev, F. Nori, E.M. Gonzalez, J.V. Anguita, R. Garcìa, J.L. Vicent, Science 302 (2003) 1188] that can easily control the motion of flux quanta in a Niobium superconducting film on an array of nanoscale triangular magnets. Even though the input ac current has zero average, the resulting net motion of the vortices can be directed along either one direction, the opposite direction, or producing zero net motion. We also consider layered strongly anisotropic superconductors, with *no* fixed spatial asymmetry, and show [S. Savel'ev, F. Nori, Nature Materials 1 (2002) 179] how, with asymmetric drives, the ac motion of Josephson and/or pancake vortices can provide a net dc vortex current. (2) In analogy with the standard macroscopic friction, we present [A. Maeda, Y. Inoue, H. Kitano, S. Savel'ev, S. Okayasu, I. Tsukada, F. Nori , Phys. Rev. Lett. 94 (2005) 077001] a comparative study of the friction force felt by vortices in superconductors and charge density waves.

Keywords: Vortex dynamics; Vortex ratchets; Spatial and temporal asymmetry; Friction

Here we summarize some recent results [1–3] obtained for vortices in superconductors and charge density waves.

1. Superconducting reversible diode that controls the motion of flux quanta

Co-authors: J.E. Villegas, E.M. Gonzalez, J.V. Anguita, R. Garcia, J.L. Vicent

We describe [1] a device that can easily control the motion of flux quanta in a Niobium (Nb) superconducting film grown on an array of nanoscale triangular pinning potentials (Fig. 1). Even though the input ac current has zero average, the resulting net motion of the vortices can be directed *along either one direction, the opposite direction, or producing zero net motion*. This controllable vortex diode effect is due to the asymmetry of the fabricated magnetic pinning centers, producing a net dc motion in one direction. The remarkable *reversal in the direction of the rectified current* is due to the *interaction* between the vortices trapped on the magnetic nanostructures and the interstitial vortices (Fig. 1). The applied magnetic field and input current strength can tune both the polarity and magnitude of the rectified current. All the observed features are explained and modeled theoretically [1,4,5] considering the interactions between particles (Fig. 2). This is the first fabricated ratchet system showing strong effects due to the *correlated motion of the interacting particles*, responsible for its current inversion.

Other recent novel ways to control vortex motion are described in [6–8].

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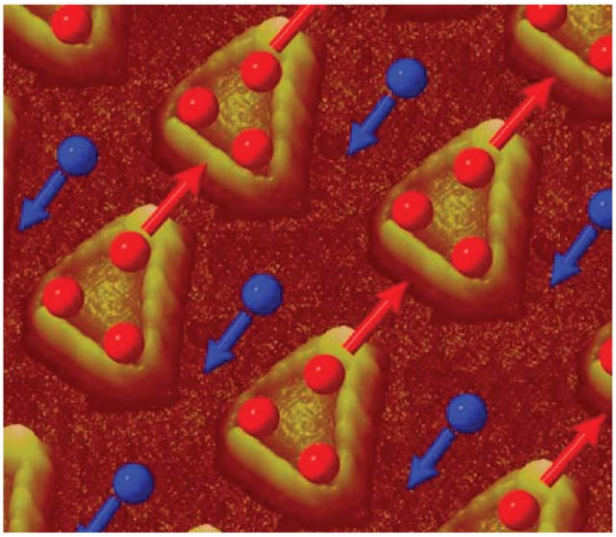

Fig. 1. Schematics of the vortex motion in a Niobium film on nano-scale-magnetic triangles [1].

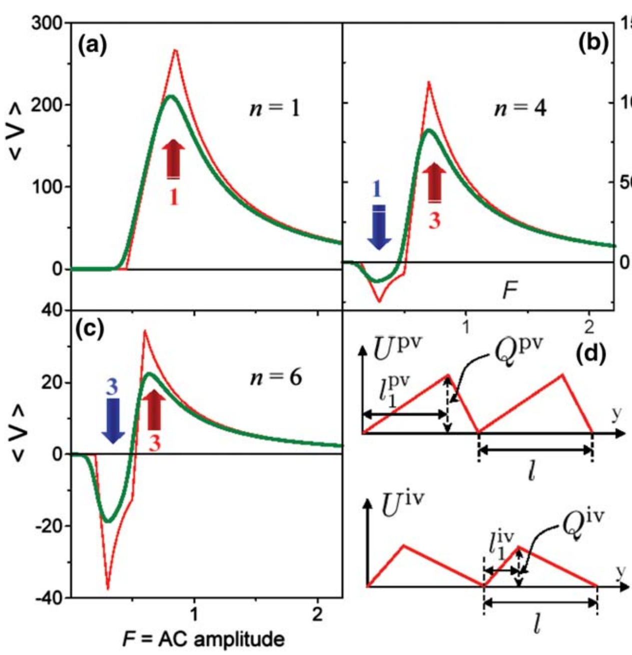

Fig. 2. (a)–(c) The calculated net dc velocity $\langle V \rangle$ versus AC amplitude F, obtained for different effective asymmetry values, using a simple model describing the mixture of pinned (pv) and interstitial (iv) vortices. Red curves are for $T = 0$ and green curves for finite T. The pinned vortices move on the asymmetric potential $U^{pv}(y)$ shown in (d top), while the interstitial vortices feel the potential $U^{iv}(y)$ shown in (d bottom). The latter potential is weaker, inverted, and originates from the interaction of the interstitial vortices with the pinned vortices [1]. (For interpretation of the references in colour in the figure legends 2 and 3 the reader is referred to the web version of this article.)

2. Experimentally realizable devices for controlling the motion of magnetic flux quanta in anisotropic superconductors

Co-authors: D. Cole, S.J. Bending, A. Grigorenko, T. Tamegai

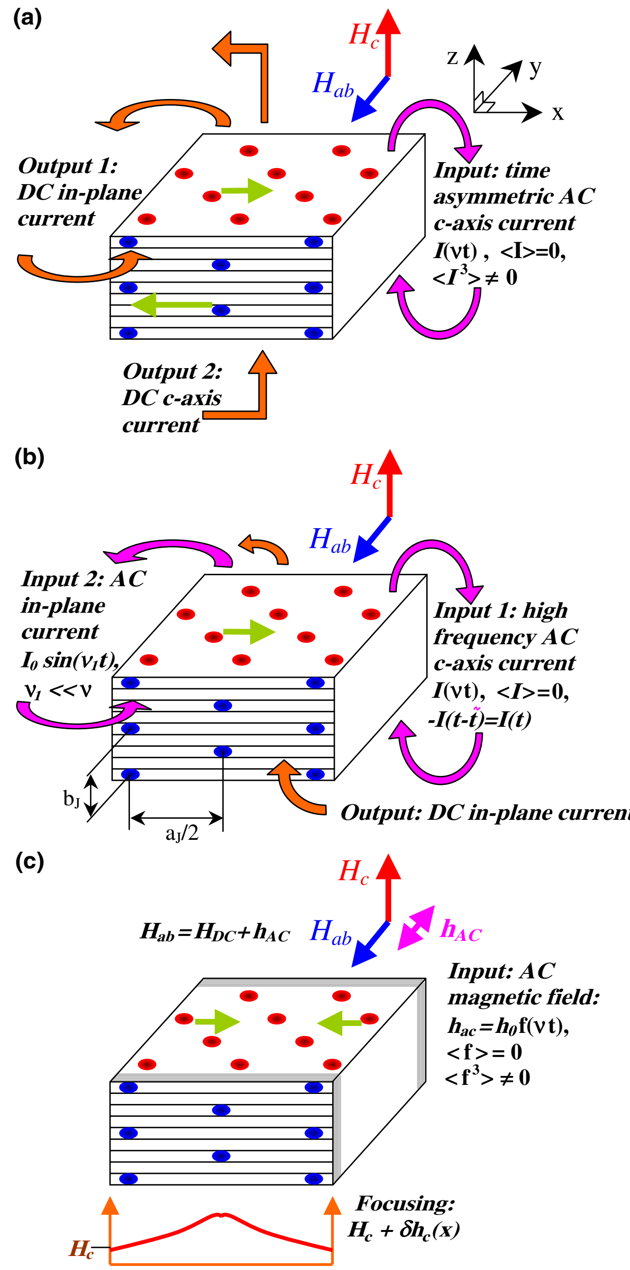

Fig. 3. Schematic diagram of three experimentally-realizable devices [2] designed for controlling the vortex motion. These use extremely anisotropic superconductors, like Bi2212, placed in magnetic fields tilted away from the *c*-axis, where there are two vortex subsystems consisting of PV stacks, indicated by red circles, and JVs, shown in blue. The vortex pump in (a) transforms the input time-asymmetric AC current flowing along the *c*-axis into in-plane and out-of-plane DC vortex currents marked by dashed green lines. The degree of temporal asymmetry of the zero-averaged $\langle I(t) \rangle = 0$ input current $I(t)$ can be quantified by its third moment $\langle I^3(t) \rangle \neq 0$. The vortex diode in (b) rectifies the applied in-plane current using the time-averaged spatially-asymmetric effective potential generated by the high-frequency oscillating JVs. The vortex lens in (c) employs an applied time-asymmetric AC magnetic field to either increase or decrease the vortex density at the center of the sample. The two irradiated edge regions with enhanced pinning, shown in gray, prevent sideways leakage of PVs.

A new generation of microscopic ratchet systems are currently being developed for controlling the motion of