Vortex Ratchets

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The concept of a ratchet and the ratchet effect has received attention in recent years in a wide variety of fields. Simply put a ratchet is formed by a particle in a potential which is asymmetric, i.e. it lacks reflection symmetry. An example is the potential shown in Figure 13, where the force to move a particle trapped in the potential is larger in one direction (the left) and smaller in the other (the right). The ratchet effect is when net transport of the particle occurs in the absence of any gradients. This can happen when the system is driven out of equilibrium, such as by an unbiased AC force or non-gaussian noise. Ratchets are of fundamental importance in biological fields, for study of dissipation and stochastic resonance, in mesoscopic systems, and in our case in superconducting Josephson systems. The key questions are to study how the transport of the particle is affected by the ratchet potential

In our group we study the ratchet effect in circular arrays of superconducting Josephson Junctions. In such arrays magnetic vortices or kinks can be trapped inside and feel a force when the array is driven by an external current. The potential that the vortex feels is given by a combination of the junction sizes and the cell areas; by varying these in an asymmetric fashion we can construct a ratchet potential for a vortex. The picture in Figure 13 is of one of our fabricated circular arrays; the potential shown in Figure 13 is the numerically calculated potential for a kink inside the array. We have verified the ratchet nature of the potential with DC transport measurements, published in early 2000.

This work is now moving in two new directions: smaller junction arrays where quantum effects are important and AC biasing or so-called rocking ratchets. A quantum ratchet will display new behavior as the temperature is lowered, as both the ratchet potential and quantum tunneling can contribute to the kink transport. We have designed and fabricated such arrays and are presently testing them. AC biasing of our arrays will cause the vortex to move and such vortex motion results in a net DC voltage across the array. In Figure 14 we demonstrated this so-called rocking ratchet, with numerical simulations and in the adiabatic limit of our previous results (DC measurements). The particle current as a function of AC biasing provides key information on the form of the ratchet potential. We plan to move in the direction of higher frequency, where more interesting structure can develop. All of these experiments are important to verify the different aspects of the ratchet effect.

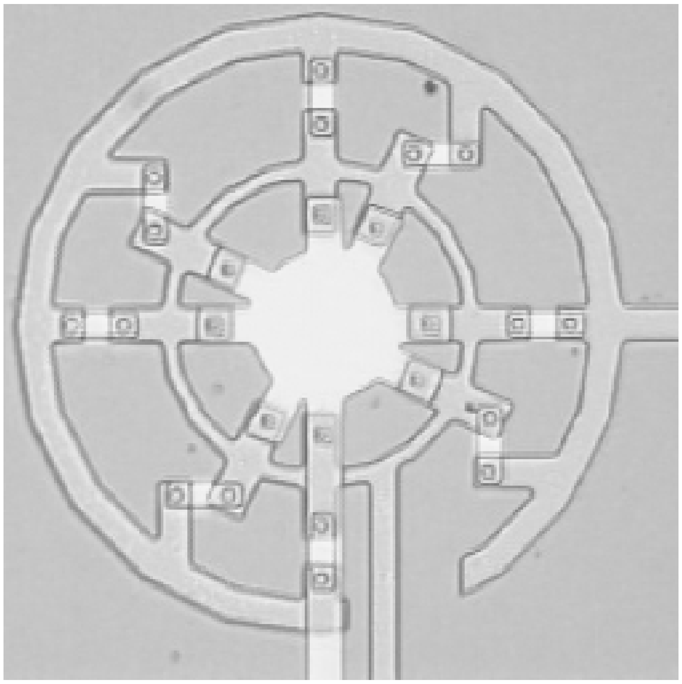
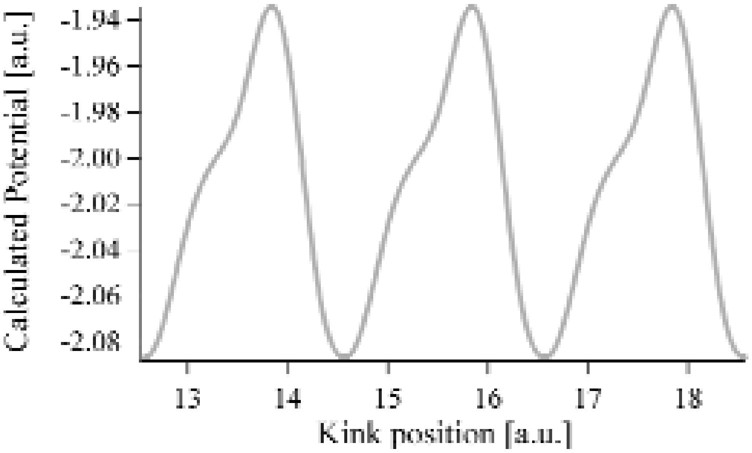


Fig.13: A ratchet potential and its realization in a Josephson array. The array has alternating junction sizes and plaquete areas to form the asymmetric potential for a vortex trapped inside the ring. The outer ring applies the current such that the vortex transport can be measured. The potential is numerically calculated for the array parameters.



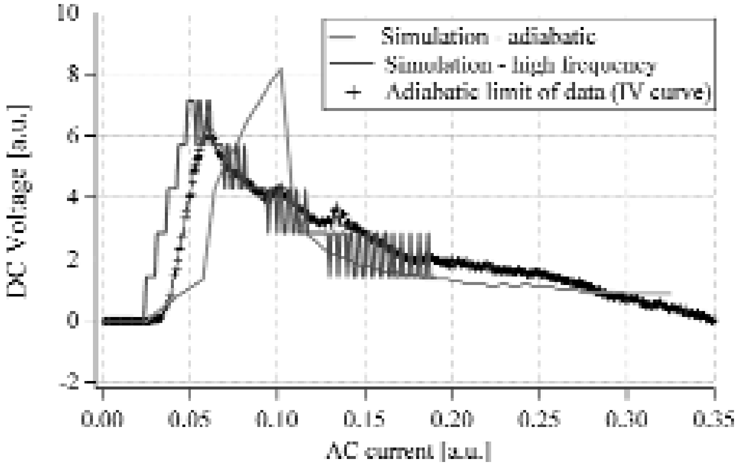


Fig. 14: Simulation and experiment for the so-called rocking ratchet, where the ratchet is subjected to an unbiased AC force. The vertical axis is the DC voltage across the circular array and is proportional to the particle (vortex) velocity. The horizontal axis is the amplitude of the AC applied force (current).