

QUANTIZED VORTICES IN SUPERFLUIDS AND SUPERCONDUCTORS

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We give a general review of recent developments in the theory of vortices in superfluids and superconductors, discussing why the dynamics of vortices is important, and why some key results are still controversial. We discuss work that we have done on the dynamics of quantized vortices in a superfluid. Despite the fact that this problem has been recognized as important for forty years, there is still a lot of controversy about the forces on and masses of quantized vortices. We think that one can get unambiguous answers by considering a broken symmetry state that consists of one vortex in an infinite ideal system. We argue for a Magnus force that is proportional to the superfluid density, and we find that the effective mass density of a vortex in a neutral superfluid is divergent at low frequencies. We have generalized some of the results for a neutral superfluid to a charged system.

1 Introduction

From the very beginning it has been realised that quantized vortices play an important part in the behavior of superfluids¹. Both in neutral superfluids and in superconductors it is the vortices that provide a mechanism for the decay of superfluid currents in a ring. The circulation, for a neutral superfluid, or the trapped flux, for a superconducting ring, is quantized, and the current can only decay by a change of the quantum number by an integer, which can occur by the passage of a vortex (or quantized flux line) across the ring, from one edge to the other. In superconductors in a high magnetic field, the motion of flux lines is the main mechanism for electrical resistance. At high temperatures the movement of vortices is a thermally activated process, but at low enough temperatures the dominant mechanism must be by quantum tunneling. It is therefore important to understand the dynamics of vortices, in order to be able to evaluate the dissipative processes that occur in neutral superfluids and in superconductors.

Despite the obvious importance of the problem, the theory has been in a most unsatisfactory state. There are many conflicting results in the literature. We did not realise the extent of this disagreement, and it was initially a surprise to us that a result we obtained would be dismissed by one knowledgeable critic as too obvious to be worth discussing, and by another equally eminent critic as well known to be wrong; this has happened to us several times. There are real problems here, connected with questions of suitable boundary conditions, and there is often a question of whether two different calculations are finding the same result by two different ways, or if they are finding two different contributions which must be