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Equilibrium current and orbital magnetization in the quantum Hall fluid

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Abstract

We present a general theory for the equilibrium current distribution in a two-dimensional interacting electron gas, subjected to a perpendicular magnetic field, and confined by a potential that varies slowly on the scale of the magnetic length. The distribution is found to generally consist of strips or channels of current, which alternate in direction, and which have universal integrated strengths.

1. Introduction

The quantum Hall effect [1] is the quantization of the off-diagonal *conductance* of a two-dimensional electronic device, at integral or simple fractional multiples of e^2/h , and the vanishing of the diagonal conductance, when a perpendicular magnetic field of appropriate strength is applied. It has long been understood [2] that this “appropriate strength” of the magnetic field is such that the Fermi level lies in a *gap* of the spectrum of bulk extended states. Finer features of the effect are not nearly as well understood. There is considerable confusion, for instance, concerning the question of the physical distribution of the Hall current in a quantum Hall device. Is the Hall current carried by “edge states” residing near the edge of the device, or is it carried by the bulk of the electron fluid? While early work [3], based on a model of non-interacting electrons, supported the first alternative, more recent work [4] taking into account Coulomb interactions self-consistently, concludes that at least a substantial part of the current is carried in the bulk. Experimental attempts to resolve the

ambiguity by directly imaging the voltage and/or current distribution, have been made [5], with no conclusive results so far. A major practical difficulty is that in a nonuniform electron fluid subjected to a magnetic field, a finite current density exists even in thermal equilibrium, due to the time-reversal symmetry breaking action of the magnetic field. Although the net current through the device is zero, its local value may be quite large – in fact larger than the Hall current density, defined as the *difference* between the total current density measured in the transport regime and the current density at equilibrium. It is evident that a clear understanding of the properties of the *equilibrium* current distribution is a prerequisite for the understanding of experiments on the Hall current distribution. In two recent papers [6, 7] we studied in detail the properties of this distribution, and found that they could be summarized in a few fairly general statements. We considered a confining potential that varies slowly on the scale of the magnetic length l : $V/l \ll \Delta$ where Δ is the minimum energy gap that we want to take into account ($\Delta = \hbar\omega_c$ if the fractional quantum Hall effect is ignored). This condition – at least insofar as the integral Hall effect is concerned – is very well satisfied in realistic devices, in which the confinement lengths are of the order of 10^4 \AA or more, while l is of the order of 100 \AA

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