Spatial Variations of the Electron Temperature in Quantum Hall Systems

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In the breakdown of the quantum Hall effect, the diagonal resistivity ρ_{xx} increases discontinuously at a critical current. Such an increase of ρ_{xx} has been ascribed to the increase of the electron temperature T_e [1]. One of interesting and important problems is to clarify spatial distributions of $T_e(x, y)$. In this paper we study spatial variations of $T_e(y)$ in the direction perpendicular to the current (the current is along x). We calculate $T_e(y)$ in the linear and nonlinear regime by applying our hydrodynamic equation [2]. We show that the electron temperature difference appears between sample edges, *i.e.* $\Delta T_e \equiv T_e(W/2) - T_e(-W/2) \neq 0$ with W the sample width. This is produced by the presence of the magnetic field and the current, and therefore it is the Ettingshausen effect in quantum Hall systems. We also show that ΔT_e exhibits quantum oscillations as a function of the filling factor and that ΔT_e *changes the sign*. These are features specific to quantum Hall systems.

In our previous work [2], we have introduced a hydrodynamic equation (nonlinear heat conduction equation) to describe macroscopic spatio-temporal variations in quantum Hall systems. An important feature of this equation is the presence of a large heat flux due to the drift motion of electrons perpendicular to the macroscopic electric field $\boldsymbol{E}$. Our equation has explained successfully the qualitative features of spatial evolutions of $\rho_{xx}(x)$ along the current which have been observed in recent experiments in the breakdown regime. In this paper, our equation is applied to spatial variations in another direction, *i.e.* perpendicular to the current.

Our microscopic model is a two-dimensional electron system in strong magnetic fields in random potential fluctuating in the scale of $\ell_{\rm vh} \sim 0.1\mu$m, in which each electron moves along the equipotential line, producing both closed orbits and extended orbits. Drift motions along extended orbits give the electric current as well as the thermal current perpendicular to the macroscopic electric field $\boldsymbol{E}$, while diffusion processes due to electron-electron scatterings give the currents parallel to $\boldsymbol{E}$.

Our major assumption in the derivation of the hydrodynamic equation is the local equilibrium in the length scale of the potential fluctuations $\ell_{\rm vh} \sim 0.1\mu$m. By making spatial averages, we obtain the equation of the energy conservation as well as that of the charge conservation. The heat flux in the equation consists of the diffusion contribution $\boldsymbol{j}_U^{\rm diff}$ parallel to $\boldsymbol{E}$ as well as the drift contribution $\boldsymbol{j}_U^{\rm drift}$ perpendicular to $\boldsymbol{E}$.

First we consider the nonlinear breakdown regime at even-integer filling factors. At even-integer filling factors, $\boldsymbol{j}_U^{\rm diff} = 0$. Since E_x is large, $\boldsymbol{j}_U^{\rm drift}$ acquires a substantial y component, which produces a difference in T_e between the two edges, ΔT_e (the Ettingshausen effect). The present asymmetric T_e distribution is consistent with the asymmetry observed in the cyclotron emission intensity distribution [1].

Next we consider the linear regime and study the filling-factor dependence of ΔT_e. Calculated ΔT_e exhibits quantum oscillations as a function of the filling factor. Interestingly, ΔT_e *changes the sign* with increasing the filling factor when the lattice temperature is low enough that $j_{Uy}^{\rm diff} \gg j_{Uy}^{\rm drift}$. This is because $\boldsymbol{j}_U^{\rm diff}$ changes the direction with increasing the filling factor .

[1] Y. Kawano and S. Komiyama: Phys. Rev. B **61**, 2931 (2000).
[2] H. Akera: J. Phys. Soc. Jpn. **69**, 3174 (2000); **70**, 1468 (2001); **71**, 228 (2002).

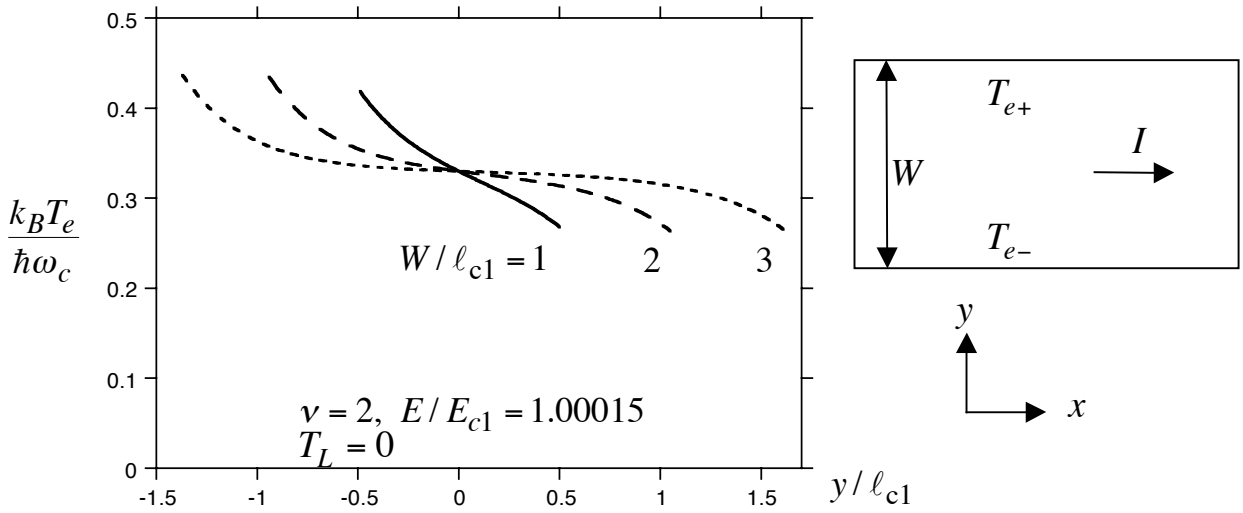

Fig. 1 Electron temperature distribution perpendicular to the current.
$\ell_{c1} \approx 2\mu$m is defined by $eE_{c1}\ell_{c1} = \hbar\omega_c$
with E_{c1} the lower critical electric field.

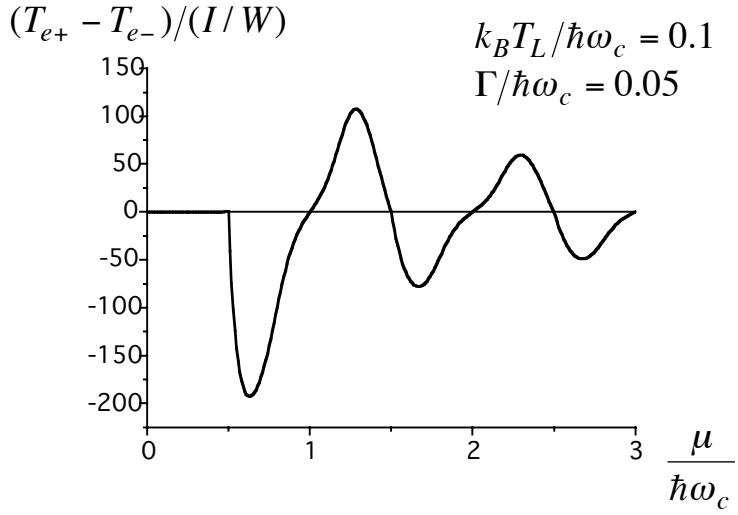

Fig. 2 Electron temperature difference between sample edges (in a dimensionless unit) as a function of the chemical potential in the linear regime.
T_L is the lattice temperature. Γ is the width of the Landau level.