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Part S5 - LT Properties of Solids 2: Electrons in 2D and weak localization

Even denominator filling factors in the thermoelectric power of a 2DEG

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We have investigated the interaction of phonons with a 2DEG in the FQH regime with phonon drag thermoelectric power (TEP). We find that the TEP at filling factors with the same even denominator is identical and at other even denominator filling factors they differ only by a constant. Assuming these states to be Composite Fermions (CF), we can explain our observations by extending a zero magnetic field theory for phonon drag to the CF-phonon interaction. This analysis is further corroborated by the observed T^4 dependence of the CF TEP.

1. INTRODUCTION

The fractional quantum Hall effect (FQHE) has recently been attributed to quantum oscillations of new quasi-particles, called Composite Fermions (CF) [1, 2]. The CF consist of an electron and an even number of flux quanta. The FQHE of the electrons can be viewed as the integer quantum Hall effect of the CF's. In particular, the magnetic field for which ν equals 1/2, appears as zero field for the CF's.
We have studied the interaction between phonons and CF's by thermoelectric power (TEP) measurements on the 2DEG. The measurements were carried out on a GaAs-AlGaAs heterostructure with density and mobility in the range of 1.0 - 1.9 x 10^{11} cm^{-2} and 0.6 - 1.0 x10^6 cm^2/Vs, respectively. A known temperature gradient was set up along the sample, which was thermally anchored to the mixing chamber of a dilution refrigerator.

2. RESULTS

In fig. 1 we present the relative thermopower $S_{xx}/S_{xx}(\nu=1/2)$ as a function of magnetic field for two temperatures. One observes that $S_{xx}(3/2)=S_{xx}(1/2)$, and that the ratio $S_{xx}(3/4)/S_{xx}(1/2)$ is about equal to 2.2. This is seen for all temperatures below about 0.5 K where the features of the FQHE become visible. For lower electron densities, where the $\nu=1/4$ state becomes visible, we observe similarly that $S_{xx}(3/4)=S_{xx}(1/4)$.
In fig. 2 we display the temperature dependence of S_{xx} at $\nu = 1/2$ and 3/2 and at B=0. Within experimental error, all three curves follow a T^4 dependence at low temperatures. At other than even denominator filling factors the low temperature behavior of S_{xx} is different from a T^4 law.

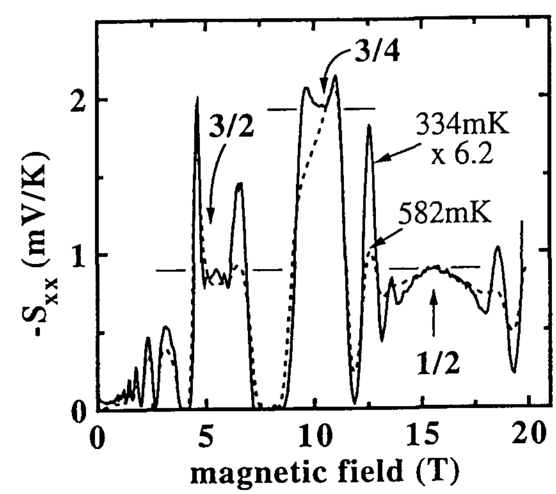

Figure 1: *Examples of the magnetic field dependence of the longitudinal component S_{xx} of the TEP. The horizontal lines mark the constant relative value for the even denominator filling factors $\nu = \frac{3}{2}$ and $\nu = \frac{3}{4}$.*

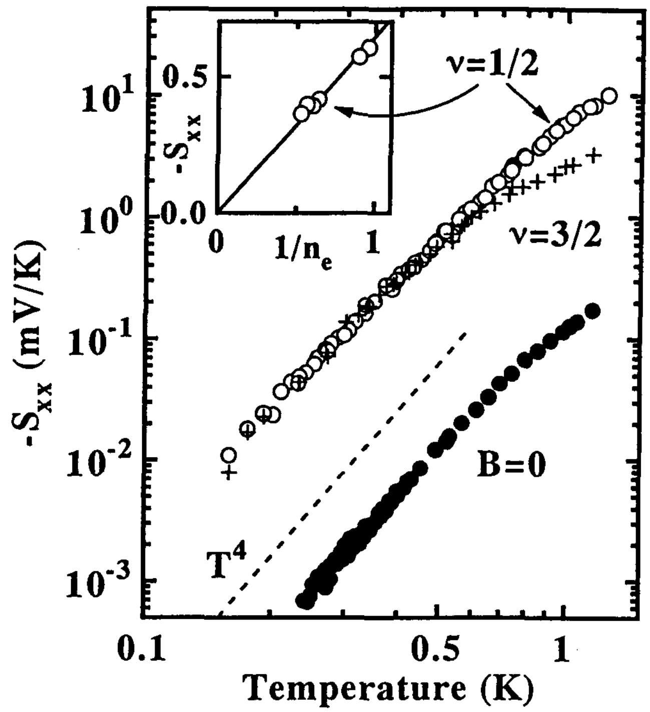

Figure 2: *The temperature dependence of the absolute value of the TEP for even denominator filling factors and zero magnetic field. The dashed curve indicates a* T^4 *dependence. The inset shows* $S_{xx}(\frac{1}{2})$ *at* $T =$ 440 *mK (in mV/K) versus the inverse density* $1/n_e$ *(in units of* 10^{-15} m^2*).*

3. DISCUSSION

We discuss first the T^4 temperature dependence of S_{xx} at ν=3/2 and 1/2. The similarity to the T-dependence at B=0 shows that phonon drag is the common origin of the TEP. It suggests furthermore that for the ν=3/2 and 1/2 states we are dealing with the phonon drag TEP of a quasi-particle (CF) in a zero effective field. This fits exactly the theory of ref. [2]: at ν=1/2 the CF's experience zero magnetic field while the ν=3/2 state is described as a half filled Landau level to which a full Landau level is added. The experimentally observed equal values for S_{xx} at 3/2 and 1/2 confirm that the CF-phonon interaction is unchanged when a full Landau level is added.

The expression for zero field phonon drag TEP derived in ref. [3] can be rewritten for the case of the CF's as [4]:

$$S_{xx} \propto T^4 \frac{m_e^*}{n_e} \int\int \frac{m_Q v_s}{\hbar k_F^Q} f(q, q_z) dq dq_z \qquad (1)$$

where m_e^* and n_e represent the effective electron band mass and the electron density, v_s is the velocity of sound in GaAs and m_Q and k_F^Q represent the CF effective mass and Fermi wave vector. In this equation $f(q, q_z)$ is a function containing the details of the scattering events, where q and q_z represent dimensionless phonon wave vectors.
Since m_Q and k_F^Q both scale as $n_Q^{1/2}$ (the quasi-particle density), this means that $S_{xx}(1/2)$ and $S_{xx}(3/2)$ are equal although n_Q differs by a factor of three between them. We also observe a $1/n_e$ dependence for the CF TEP, while for the zero field TEP we observe rather something in between $1/n_e^{1.5}$ or $1/n_e^2$ corresponding to the fact that for zero field m_Q is replaced by m_e^*, which is independent of the density.

4. CONCLUSIONS

We have demonstrated that the even denominator filling factor TEP can be described as the phonon drag TEP of CF's. All our experimental observations are explained by a zero field field expression for the phonon drag TEP of CF's in support of the theoretical concept of these quasi-particles as fermions in zero field.

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