Electrical transport of composite fermions at $\nu=\frac{3}{2}$

V. C. Karavolas and G. P. Triberis
University of Athens, Physics Department, Solid State Section, Panepistimiopolis, 15784 Zografos, Athens, Greece
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The resistivity is calculated for a two-dimensional electron gas at low temperatures in the fractional quantum Hall effect regime at a filling factor $\nu=\frac{3}{2}$. The composite fermion picture enables us to use the integer quantum Hall effect and Shubnikov–de Haas (SdH) conductivity models for a quantitative comparison with experiment. We use the idea of parallel conduction of two gases. One gas, composed of electrons, fully occupies one of the two spin levels of the lowest Landau level, and a second, composed of composite fermions, partially occupies the other spin level. Two different formulas for the analysis of the SdH oscillations are used for the weak effective magnetic-field region and the large magnetic-field region, respectively, and satisfactory agreement with experiment is obtained. Comparison with the $\nu=\frac{1}{2}$ case is made.

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I. INTRODUCTION

The quantization of the Hall effect, discovered by von Klitzing *et al.*[1] in 1980, is a remarkable macroscopic quantum phenomenon which occurs in two-dimensional electron systems and strong perpendicular magnetic fields. Under these conditions, the Hall conductivity exhibits plateaus at integral multiples of e^2/h (a universal constant). The striking result is the accuracy of the quantization (better than a part per million) which is totally indifferent to impurities or geometric details of the two-dimensional system. Each plateau is accompanied by a deep minimum in the diagonal resistivity, indicating a dissipationless flow of current. In 1982, there was another surprise in the field. Working with much higher mobility samples, Tsui *et al.*[2] discovered the fractional quantization of the Hall conductivity. The physical mechanisms responsible for the integer quantum Hall effect (IQHE) and the fractional quantum Hall effect (FQHE) are quite different, despite the apparent similarity of the experimental results. In the former case, the role of the random impurity potential is quite decisive, while in the latter case electron-electron interaction plays a predominant role resulting in a unique collective phenomenon. The FQHE was realized in high-mobility two-dimensional electron gas (2DEG) in $GaAs/Al_xGa_{1-x}As$ heterostructures,[2–5] and in high-mobility Si metal-oxide-semiconducter field-effect transistors.[6,7] The FQHE was also observed in multiple-quantum-well heterostructures[8] and in n-type Si/SiGe heterostructures.[9] At very low temperatures and high magnetic fields, an increasing number of Hall plateaus were observed, corresponding to fractional filling factors with odd denominators.

The major breakthrough in this problem was made by Laughlin,[10] who proposed a Jastrow-type trial wave function for a $\nu=1/m$ filling factor, with m an odd integer. Based on this wave function, he also proposed the low-lying elementary excitations to be quasiparticles and quasiholes of fractional charge.

A very promising approach to understand a system near even denominators is to attach to each particle an even number of ''flux quanta.'' In this way a new quasiparticle called the ''composite fermion'' (CF) was created. This is based on the idea of the transmutability of the statistics for particles in two-dimensional systems.[11] It is possible to introduce a Chern-Simons gauge field that interacts with the carriers, resulting in a change of their statistics. The method is equivalent to the attachment of a ''magnetic flux tube'' to each carrier. As a result the quantum-mechanical properties of the new particle are the same as those of the conventional particles.

Jain,[12,13] following this idea and attaching even numbers of flux quanta to each electron, successfully constructed the hierarchy of the FQHE through the equation

$$\nu=\frac{\nu^*}{2m\nu^*\pm 1}, \tag{1}$$

where, ν is the filling factor, $2m$ is the number of attached flux quanta, and ν^* a positive integer. The remarkable property of this idea is that instead of the FQHE for the actual carriers, at filling factor ν, we study the IQHE for CF's, at filling factor p. As a result, the whole arsenal of ideas used to understand the IQHE are applicable to the FQHE. In a previous work,[14] we presented calculations for the diffusion transport coefficients for a 2DEG and a two-dimensional hole gas, at low temperatures, near $\nu=\frac{1}{2}$.

For the interpretation of the experimental data of Leadley *et al.*[15] and Du *et al.*,[16] we used two different models, Isihara and Smrčka (IS)[17] and Englert,[18] within the CF representation. The IS model reproduces quite well the transport coefficients, magnetoresistance (for electrons) and diffusion thermopower (for holes), around a filling factor $\nu=\frac{1}{2}$, at temperatures lower than 0.3 K at the weak effective magnetic-field region, where the Englert model fails. The latter succeeds quite well in the large effective magnetic-field region, where the IS model fails, especially for ρ_{xy} and S_{xx}.

The $\nu=\frac{3}{2}$ case is different than the $\nu=\frac{1}{2}$ case. This is due to the fact that the magnetic field is inadequate to transform all the carriers to CF's, as in the $\nu=\frac{1}{2}$ case. Our analysis is based on the discrimination of the carriers in two different gases, showing parallel conduction. The first consists of electrons which fully occupy one of the two spin levels of the lowest Landau level, and the second consists of electrons which have been transformed to CF's, partially occupying the other spin level. Based on the above we use IS and Englert models to interpret the experimental data for the resistivity of Eisenstein *et al.*[19]

In the present work we calculate the resistivity, at low temperatures, near $\nu=\frac{3}{2}$. The present paper consists of the following: A brief description of the models used together with the physical assumptions, relevant to the $\nu=\frac{3}{2}$ case, is presented in Sec. II for low- and high-magnetic-fields. In Sec. III we present our results, and we compare them with the $\nu=\frac{1}{2}$ case and with the experimental data.[19] Finally, in Sec. IV, we present our conclusions.

II. THEORY

In the simplest case studied by Jain, with the charges occupying only the lowest Landau level, we can understand the fermion FQHE states as IQHE states at $\nu=1/2m$ for CF's in an effective magnetic field ΔB given by

$$\Delta B = B - B_{1/2} = \frac{2\pi\hbar c}{e}\frac{n_e}{\nu^*}, \tag{2}$$

where n_e is the fermion concentration, ν^* is now the CF filling factor, and $-e$ is the electron's charge.

A very important result from the theory is that the conductivities for the electrons in the FQHE and for the CF's in the IQHE are *added in parallel*.[11,20] This result is very crucial in our attempt at a quantitative comparison with experiment. Then the resistivity tensor can be written as

$$\rho = \begin{bmatrix} \rho_{xx}^{qp} & -\rho_{xy}^{qp} - \rho_{CS} \\ \rho_{xy}^{qp} + \rho_{CS} & \rho_{xx}^{qp} \end{bmatrix}, \tag{3}$$

where ρ_{CS} is the term in the nondiagonal resistivity, arising from the statistical potential,

$$\rho_{CS} = \frac{2\pi\hbar s}{e^2}, \tag{4}$$

ρ_{xy}^{qp} is the nondiagonal quasiparticle CF's IQHE conductivity term, ρ_{xx}^{qp} is the quasiparticle diagonal conductivity of the CF's, and s is the number of flux quanta attached to each carrier. ρ_{xx} and ρ_{xy} are calculated using the same models as those we used to describe the carriers Shubnikov–de Haas (SdH) oscillations and the IQHE resistivity tensor, substituting only the carrier parameters for the CF ones, and replacing the actual magnetic field with the effective field given by Eq. (2) used for the study at $\nu=\frac{1}{2}$.

The system under study consists of N electrons moving on a plane (x,y) in the presence of an external magnetic field $B=(0,0,B_z)$ perpendicular to the plane. We will consider only the case when the magnetic field is so high that all the carriers populate the two lowest spin levels of the lowest Landau level.

At $\nu=\frac{3}{2}$, for this system, the effective field is approximated using, instead of Eq. (2), the following equation[21,22]

$$\Delta B = 3(B - B_{3/2}). \tag{5}$$

We will treat the system under study as two different gases, showing parallel conduction. One gas is composed of electrons which fully occupy one of the two spin levels of the lowest Landau level, and the other gas is composed of electrons which have been transformed to composite fermions which partially occupies the other spin level.

As the actual magnetic field changes, the concentration of each gas changes following the equation

$$n_{tot} = n_{cf} + n_{el}, \tag{6}$$

where n_{tot} is the total electron concentration, n_{cf} is the composite fermion concentration, and $n_{el}=eB/h$ is the fully occupied Landau-level electron concentration.

From Eq. (6), and the fact that the electron concentration of the fully occupied spin level is field dependent, the field resulting in a filling factor $\nu=\frac{1}{2}$ for the composite fermion gas will also be field dependent, given by

$$B_{1/2} = \frac{2hn_{cf}}{e}. \tag{7}$$

Thus the effective magnetic field for this gas will be given by

$$\Delta B = B - B_{1/2} = B - \frac{2hn_{cf}}{e}. \tag{8}$$

In this model the two gases are conducting in parallel. The total current in the case of a parallel connected multilayer system is the sum of the currents in the different layers. Consequently, the total sheet conductivity is the sum of the sheet conductivities of the separate layers.[23] If the conductivity of layer i is given by

$$\tilde{\sigma}_i = \begin{pmatrix} D_i & -A_i \\ A_i & D_i \end{pmatrix}, \tag{9}$$

where D_i is the diagonal component of the layer i conductivity, and A_i is the nondiagonal component.

The total conductivity of the two-layer system is

$$\tilde{\sigma}_{tot} = \tilde{\sigma}_1 + \tilde{\sigma}_2 = \begin{pmatrix} (D_1+D_2) & -(A_1+A_2) \\ (A_1+A_2) & (D_1+D_2) \end{pmatrix}. \tag{10}$$

After inverting the above equations, for the resistivity we obtain

$$\rho_{xx} = \frac{D_1+D_2}{(D_1+D_2)^2+(A_1+A_2)^2} \tag{11}$$

and

$$\rho_{xy} = -\frac{A_1+A_2}{(D_1+D_2)^2+(A_1+A_2)^2}. \tag{12}$$

In the *low-magnetic-field* range, the SdH oscillations of the resistivity ρ_{xx}, for a single subband, can be described by the model of Isihara and Smrčka,[17] which was corrected by Coleridge and Stoner,[24] who introduced different relaxation times. For the calculation of the conductivity a constant density of states (DOS) $g_0=m^*/\pi\hbar^2$ (m^* is the effective mass), with a sinusoidal oscillating part superimposed, has been used. The oscillating part of the DOS reflects the onset of the Landau levels, and leads to SdH oscillations of the magnetoconductivity. The conductivities in this model are given by

$$\sigma_{xx}=\frac{\sigma_0}{1+\omega_c^2\tau_s^2}\left(1+\frac{2\omega_c^2\tau_s^2}{1+\omega_c^2\tau_s^2}\frac{\Delta g}{g_0}\right), \tag{13a}$$

$$\sigma_{xy}=\frac{\sigma_0\omega_c\tau}{1+\omega_c^2\tau_s^2}\left(1-\frac{1+3\omega_c^2\tau_s^2}{(1+\omega_c^2\tau_s^2)\omega_c^2\tau_s^2}\frac{\Delta g}{g_0}\right), \tag{13b}$$

$$\frac{\Delta g}{g_0}=2\sum_{r=1}^{\infty} e^{-\pi r/\omega_c\tau_q}\frac{rX}{\sinh(rX)}\cos\left(\frac{2\pi r E_F}{\hbar\omega_c}-\pi r\right). \tag{14}$$

The complete theory was presented elsewhere.[14,25]

This model is valid for low and intermediate fields such that $\omega_c\tau_q\leqslant 1$. Using the above expressions for ω_c and the definition of the mobility ($\mu=e\tau_s/m^*$), we can substitute in Eqs. (13a) and (13b) the term $\omega_c\tau_s$, with μB, while in the DOS the term $\omega_c\tau_q$ can be expressed as $\mu_q B$. For larger magnetic fields the localization of the electrons away from the center of the Landau level starts to play an important role, and the above model will no longer be applicable.

In these model calculations both the scattering time $\tau_s=m^*\sigma_0/e^2n_e$ and the quantum lifetime τ_q are present. In modulation-doped 2D systems they can differ by more than an order of magnitude.[26–29] In the case of short-range scattering, these two times are equal. The zero-field conductivity $\sigma_0=n_e\mu e$ is determined by the scattering time τ_s, while the zero-field single-particle relaxation time or quantum lifetime τ_q is present in the oscillatory part of the DOS.

For sufficiently *large magnetic fields* applied to 2D systems, ρ_{xx} becomes vanishingly small, and ρ_{xy} shows plateaus, in finite ranges of the magnetic field, when E_F lies between two separated Landau levels. σ_{xx} and σ_{xy} for *high effective magnetic fields* are given by

$$\sigma_{xx}=\frac{e^2}{\pi^2\hbar}\sum_{N,s}\int dE\left(-\frac{\partial f(E)}{\partial E}\right)\times\left[\frac{\Gamma_N^{xx}}{\Gamma_{N,s}}\right]^2[\pi^2 l^2\Gamma_{N,s}D_{N,s}(E)]^2, \tag{15a}$$

$$\sigma_{xy}=-\frac{e}{B}\sum_{N,s}\int dE f(E)D_{N,s}(E). \tag{15b}$$

The complete theory was also presented elsewhere.[14,25]

The conductivity of the electrons which fully occupy the lowest spin level of the lowest Landau level is given by

$$\tilde{\sigma}_{el}=\begin{pmatrix} D_1 & -A_1\\ A_1 & D_1\end{pmatrix}=\begin{pmatrix} 0 & -\dfrac{e^2}{h}\\ \dfrac{e^2}{h} & 0\end{pmatrix}. \tag{16}$$

On the other hand the total conductivity of the composite fermions should be calculated from the inversion of the resistivity tensor from Eqs. (3); thus the conductivity of the composite fermion gas is

$$\tilde{\sigma}_{cf}=\begin{pmatrix} D_2 & -A_2\\ A_2 & D_2\end{pmatrix}=\begin{pmatrix} \dfrac{\rho_{xx}^{qp}}{(\rho_{xx}^{qp})^2+(\rho_{xy}^{qp}+\rho_{CS})^2} & -\dfrac{(\rho_{xy}^{qp}+\rho_{CS})}{(\rho_{xx}^{qp})^2+(\rho_{xy}^{qp}+\rho_{CS})^2}\\ \dfrac{(\rho_{xy}^{qp}+\rho_{CS})}{(\rho_{xx}^{qp})^2+(\rho_{xy}^{qp}+\rho_{CS})^2} & \dfrac{\rho_{xx}^{qp}}{(\rho_{xx}^{qp})^2+(\rho_{xy}^{qp}+\rho_{CS})^2}\end{pmatrix}, \tag{17}$$

where

$$\tilde{\rho}_{qp}=\begin{pmatrix} \rho_{xx}^{qp} & -\rho_{xy}^{qp}\\ \rho_{xy}^{qp} & \rho_{xx}^{qp}\end{pmatrix}=\begin{pmatrix} \dfrac{\sigma_{xx}}{\sigma_{xx}^2+\sigma_{xy}^2} & -\dfrac{\sigma_{xy}}{\sigma_{xx}^2+\sigma_{xy}^2}\\ \dfrac{\sigma_{xy}}{\sigma_{xx}^2+\sigma_{xy}^2} & \dfrac{\sigma_{xx}}{\sigma_{xx}^2+\sigma_{xy}^2}\end{pmatrix}. \tag{18}$$

The contribution to the total resistivity of the electrons fully occupying the lowest spin level of the lowest Landau level modifies the equation of the magnetoresistance used for the $\nu=\frac{1}{2}$ case. The total resistivity of the system is given by Eqs. (11) and (12).

III. RESULTS

In order to compare our calculations with the experimental data quantitatively we have to know the exact value of the CF effective mass for each sample. Halperin *et al.*[20] and Ambrumenil and Morf[30] calculated the effective mass, and found values around $m^*=0.3m_e$, where m_e is the free-electron effective mass. They also found that this depends on the electron concentration. Halperin *et al.* also predicted that the CF effective mass is field dependent. Gee *et al.* also found that the effective mass depends on the angle and the confining potential in tilted fields.[31]

In Fig. 1 we present the calculated diagonal component of the resistivity in comparison with the experimental data of Eisenstein *et al.*[19] for both theoretical models. The effective mass used is $m^*=0.43m_e$. The mobility used in our calculations was obtained from the experimental ρ_{xx} values at $\nu=\frac{3}{2}$. Although the diagonal conductivity D_1 of a fully occupied Landau level is zero, as is the nondiagonal component

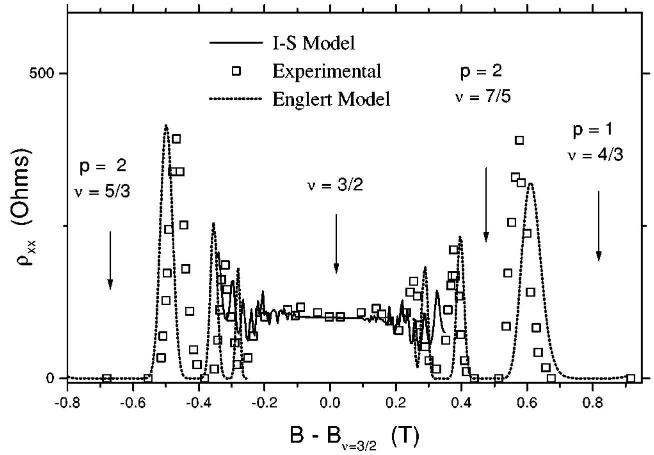

FIG. 1. Calculated ρ_{xx} at 0.025 K compared with experimental data of Eisenstein *et al.* (Ref. 19) for different theoretical models. The squares represent the experimental data, the full line shows the theoretical calculations using the Isihara-Smrčka model, and the dotted line shows the theoretical calculations using the Englert model.

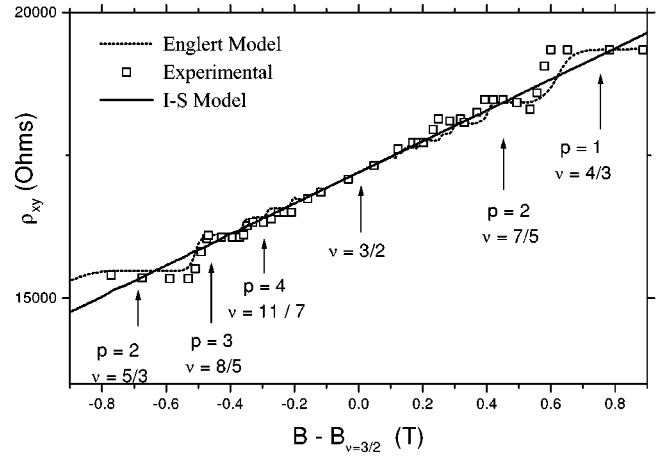

FIG. 2. Calculated ρ_{xy} at 0.025 K compared with experimental data of Eisenstein *et al.* (Ref. 19) for different theoretical models using the same values of the parameters as those used in Fig. 1. The full line shows the results for the Isihara-Smrčka model, and the dotted line shows the results for the Englert model.

of the composite fermion conductivity A_2, the total ρ_{xx} at $\nu=\frac{3}{2}$, given by Eq. (11), is

$$\rho_{xx}=\frac{D_1+D_2}{(D_1+D_2)^2+(A_1+A_2)^2}=\frac{D_2}{(D_2)^2+(A_1)^2}, \quad (19)$$

where the nondiagonal conductivity is A_1 nonzero and equal to e^2/h. Thus the above result for the ρ_{xx} is different from the quasiparticle ρ_{xx}^{qp} at zero magnetic fields,

$$\rho_{xx}^{qp}=\frac{D_2}{(D_2)^2+(A_2)^2}=\frac{D_2}{(D_2)^2}, \quad (20)$$

where $D_2=ne\mu$. This behavior is different from the $\nu=\frac{1}{2}$ case, where the entire $B_{eff}=0$ ρ_{xx} comes from the quasiparticle contribution. Thus we cannot use the semiclassical formula

$$\rho_{xx}=\frac{1}{ne\mu} \quad (21)$$

to obtain a value for the composite fermion mobility, because if we consider that the total number of electrons are transformed to composite fermions, the mobility obtained from Eq. (21) is 27 $m^2/V\,s$. If we consider that the electrons transformed to composite fermions are those which partially occupy the upper-spin Landau level, the mobility obtained is 81 $m^2/V\,s$. It is the idea of parallel conduction, introduced above, which leads to Eq. (19), that permits one to use this equation to obtain the correct value for the mobility, i.e., 9 $m^2/V\,s$ (Table I) for a consistent interpretation of the experimental data.

It is obvious from Fig. 1 that the range of the validity of the Isihara-Smrčka model is limited to a small range around $B=B_{3/2}$. This can be understood from the criterion of validity of the specific model:[24]

$$B_{eff}\mu_q \leqslant 1. \quad (22)$$

For these filling factors the effective magnetic field increases more quickly than the difference $B-B_{3/2}$ [Eq. (8)]. Thus, for a quantum mobility $\mu_q=2.1$ $m^2/V\,s$ (Table I) the $B-B_{3/2}$ range where the above model is valid is less than 0.2 T, where no peaks are observed. Consequently we cannot use this model to extrapolate for larger field values to obtain the observed peaks in the experimental ρ_{xx} behavior around $\nu=\frac{3}{2}$. On the other hand, the Englert model completely fails near $B=B_{3/2}$, but it explains the higher field oscillations quite well, and with it we obtained the magnitude of the observed peaks with considerable accuracy.

Our calculation was performed assuming that the composite fermion gas is not spin polarized. It was previously shown that a transition from spin-polarized to spin-unpolarized gas occurs around $\nu=\frac{8}{5}$ up to $\nu=\frac{4}{3}$.[21,22] Thus it is not unphysical to assume that the composite fermion gas for $\nu=\frac{3}{2}$ is always spin unpolarized. We have used the free-electron value for the effective spin splitting parameter ($g^*=0.42$). We believe that the fact that our agreement is worse at positive effective fields compared with the agreement at negative effective fields is due to our assumption for g^*. Du *et al.*[21] proposed a field-dependent effective spin-splitting factor. Such a factor would have to include another parameter in our calculation, and we decided to neglect it.

In Fig. 2 we present theoretical results of ρ_{xy} versus the magnetic field, using both models, for the same values of the parameter as those used to obtain Fig. 1. From Eq. (14) it is clear that the important factor in the oscillations is the quantum mobility. Thus, from these data, we can deduce the quantum mobility value but not the effective mass. It is obvious that the Englert model reproduces the plateaus in the nondiagonal resistivity quite well, while the Isihara-Smrčka model does not. The plateaus are at the correct positions, and ρ_{xy} has the expected values, frequently observed in experiments.[25] Our model explains quite well both the diagonal and nondiagonal behaviors of conductivity, in contrast

TABLE I. Parameters used for the calculation of the resistivities of Eisenstein *et al.* (Ref. 19) around $\nu=\frac{3}{2}$.

	Figs. 1 and 2
Fitting parameters	
$\Gamma_{N,s}$ (meV)	$0.1\sqrt{B_{eff}/\mu_q}$
$\lambda_{N,s}$ (meV)	$0.025\sqrt{B_{eff}/\mu_q}$
$\Gamma_{N,xx}$	0.9
Physical parameters	
μ (m^2/V s)	9.0
μ_q (m^2/V s)	2.10
n_e ($\times 10^{15}$ m^{-2})	2.3
$m^*(m_e)$	0.43
n_{CF} ($B_{\rm eff}=0$)($\times 10^{15}$ m^{-2})	0.77

with previous analysis, which was based only on the construction of the FQHE states hierarchy and explained only the ρ_{xy} behavior.[19,21] Our agreement with the experimental data is very good, especially at negative effective fields.

The parameters used for the calculations are shown in Table I. Because of the fact that the scattering is of medium to short range, the mobility is only four times larger than the quantum mobility. This explains the value of $\Gamma^2_{N,xx}$ being 0.9. Ando *et al.*[32] found that this parameter is Landau level dependent when the scattering is not short ranged. In our attempt to limit the number of parameters used in our calculations, we assumed that $\Gamma^2_{N,xx}$ has the same value at every Landau level. This is not artificial because Ando *et al.*'s result showed that only the lowest Landau level, for which the Englert model is not working well, shows a constant $\Gamma^2_{N,xx}=1.0$ while the other Landau-level values $\Gamma^2_{N,xx}$ are between 0.5 and 0.9.

Again the Isihara-Smrčka model works quite well at low effective fields, but shows some peculiar behavior ($\rho_{xx}<0$) at higher fields. The Englert model shows the opposite behavior. Thus one has to be quite careful which one of the models one uses, attempting to analyze experimental data or extract values of the effective mass. The validity of the Isihara-Smrčka model is rather limited, especially at high effective fields.[24]

In Table II we present the corresponding parameters for the $\nu=1/2$ case. A meaningful comparison (although the data refer to different temperatures) can be made between the data of Leadley *et al.*[15] and Eisenstein *et al.*,[19] given that their $n_{CF}(B_{eff}=0)$ values are close enough. In both cases the effective-mass values are close, as well as the values of the quantum mobility (μ_q). The difference in the mobility

TABLE II. Parameters used for the calculation (Ref. 14) of the resistivities for the data of Leadley *et al.* (Ref. 15) and Du *et al.* (Ref. 16) around $\nu=\frac{1}{2}$.

	Leadley *et al.*	Du *et al.*
Fitting parameters		
$\Gamma_{N,s}$ (meV)	$1.5\sqrt{B_{eff}/\mu_q}$	$1.0\sqrt{B_{eff}/\mu_q}$
$\lambda_{N,s}$ (meV)	$0.25\sqrt{B_{eff}/\mu_q}$	$0.25\sqrt{B_{eff}/\mu_q}$
$\Gamma_{N,xx}$	0.6	0.6
Physical parameters		
μ (m^2/V s)	12.10	5.74
μ_q (m^2/V s)	2.25	1.0
n_e ($\times 10^{15}$ m^{-2})	0.6	2.25
$m^*(m_e)$	0.51	0.90
n_{CF} ($B_{\rm eff}=0$)($\times 10^{15}$ m^{-2})	0.6	2.25

(μ) values is consistent with the corresponding values of $\Gamma_{N,xx}$. $\Gamma_{N,xx}$, for the $\nu=\frac{3}{2}$ case, is closer to unity than in the $\nu=\frac{1}{2}$ case, indicating a scattering of shorter range,[32] i.e., smaller scattering times[33] and consequently lower mobilities. The difference in the values of the Landau-level broadening, $\Gamma_{N,s}$, indicates the different quality of the samples.

IV. CONCLUSIONS

Our theoretical results show a very good quantitative agreement with the experimental data for the electronic magnetoresistance at $\nu=\frac{3}{2}$ and at temperatures 0.025 K. For the interpretation of the experimental data, we used two different models (Isihara-Smrčka and Englert) within the CF representation, and we investigated their range of validity.

The Isihara-Smrčka model reproduces quite well the transport coefficient behavior in the low effective field regime, where the Englert model fails. The latter model succeeds quite well at high effective magnetic fields, where the Isihara-Smrčka model fails, especially for ρ_{xy}.

In order to extract values the composite fermion effective mass or mobilities, we have to take into account the nondiagonal contribution of the lowest-Landau-level conductivities.

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