Angular dependent measurements of the $\nu = 5/2$ fractional quantum Hall effect state at ultra-low temperatures

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Abstract

The spin polarization of the obscure even-denominator FQHE state at $\nu = 5/2$ remains an open, but important question to answer. One method to address this question is to measure the angular dependence of its energy gap. Since the energy gap at $\nu = 5/2$ is rather small, this kind of experiments is technically extraordinary challenging, due to the requirement of *in situ* rotation of the sample at ultra-low temperatures. We constructed a rotator, made from polycarbonate and operated hydraulically using liquid ^{3}He. A sequence of experiments at $\nu = 5/2$ clearly demonstrated the possibility of performing angular-dependent measurements at temperatures below 10mK.

Key words: fractional quantum Hall effect; even-denominator ; ultra-low temperature ; rotator

1. Introduction

It is of great interest to study the spin polarization of the even-denominator fractional quantum Hall effect state at $\nu = 5/2$, by measuring the angular dependence of its energy gap. Since the energy gap at $\nu = 5/2$ is rather small, this kind of experiment is technically challenging, duo to the requirement of the in situ rotation of the sample at ultra-low temperatures (T<10 mK). We have developed a miniature sample rotator, which to our knowledge is the first device that operates below 10 mK. It rotates the sample about one axis more than 90 degrees with an accuracy of 0.2 degrees.

In this unique device, the main objective is to minimize the thermal dissipation generated by frictional motion. To meet this requirement, commercially available ruby, sapphire vee jewels, and nivapoint pivots are used as frictional bearings in all moving joints. Hydraulic pressure is chosen as the driving force to avoid a heat load from high temperatures. Indeed, with these advantages the rotator performed well without significant heating down to our dilution refrigerator base temperature of 8.0 mK.

2. Construction and Performance

The rotator consists of a BeCu bellow, two pure silver posts (one large and one small in diameter), a sample plate and a holder both made of polycarbonate. One end of the bellow is glued to the holder with Stycast 2850 and other end is soft soldered to the large silver post. The small silver post, with sapphire ring jewel in one end, and a sapphire rod together form a “T” shaped joint connected to the sample plate. Its details

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are shown in Fig.1 with views from different angles. The rotator is then attached at the bottom of the experimental cell, which is thermally connected to the nuclear refrigerant stage. The rotation mechanism is driven by compressed liquid helium three (^3He) through a capillary, with a small capacitive strain gauge in as the indicator of liquid pressure.

The rotator was first tested and calibrated at the liquid nitrogen temperature by directly measuring the change of angle of the sample plate with a capacitive pressure sensor and the driving pressure. An Andeen-Hagerling 2500A capacitance bridge and a Parocientific Digiqurtz pressure gauge were used to read the capacitance and the applied pressure, respectively. The initial angle of sample plate was positioned at negative 10 degrees with the pressure of zero bar, and it turned to vertical at 5.240 bar. Hysteresis was found to be negligible during pressure increasing and decreasing.

The rotator worked very well at ultra-low temperatures. The rotation angle is calibrated by comparing the position of magneto-resistance minimum of a quantum Hall effect state, which only depends on the perpendicular magnetic field, $B_{perp} = B_{total} \times \cos(\theta)$, where B_{total} is the total field where the QHE minimum occurs. At 8.0 mK, the rotator was operated up to full pressure and down to zero several times. It showed excellent reproducibility and precision of the pressure and capacitance. Approximately one hour is required to turn the sample to 90° from 0°. The turning speed is limited by the slow condensation of ^{3}He gas. During this time the change of the temperature was found to be less than 50 μK as indicated by a calibrated ^{3}He melting pressure thermometer (MPT).

3. Experimental Results

The 4.0 mm × 4.0 mm × 0.5 mm GaAs/$Al_x Ga_{1-x}$As sample is mounted in the center of the plate. Eight sintered silver powder heat exchangers are used to cool the two-dimensional electron gas (2DEG) with the same construction as Ref. [1,2], but are shorter to fit the plate and are tied down on the plate with cotton threads. Each electrical contact of the sample is directly soldered to the center silver wire of the heat exchanger with indium. To make the electrical connection from the leads coming from outside of the cell, 14 silver wires, with diameter in 0.25 mm, are fed through the holder. Fine copper wires with proper length then make the connections between the heat exchangers and the silver wires.

In Figure 2, four traces of R_{xx} around $\nu = 5/2$ are plotted against B_{perp} and the corresponding tilt angle is also indicated. The strong minimum at $\nu = 5/2$ shifts to higher magnetic field as the sample is tilted.

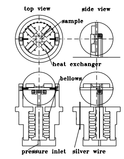

Fig. 1. Construction details of rotator.

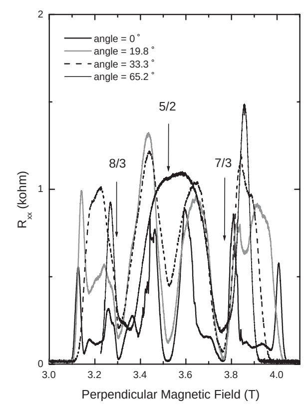

Fig. 2. R_{xx} versus total magnetic field at different angles. Sample is a GaAs/AlGaAs quantum well.

Magneto-resistance was also measured along and perpendicular to the in-plane field at several tilt angles. We note that the isotropic states of $\nu = 5/2, 7/2$ become anisotropic in the presence of in-plane field and the hard axis (the high resistance direction) is always along the in-plane magnetic field direction. This is consistent with previous experimental findings and theoretical calculations [3–5].

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