Realization of a Laughlin Quasiparticle Interferometer: Observation of Anyonic Statistics

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Abstract. We report experimental realization of a novel Laughlin quasiparticle interferometer, where quasiparticles of the 1/3 fractional quantum Hall fluid encircle an island of the 2/5 fluid. Interference fringes are observed as conductance oscillations, as in the Aharonov-Bohm effect. For the first time, we observe an Aharonov-Bohm superperiod of five magnetic flux quanta ($5h/e$) through the island. The corresponding $2e$ charge period is confirmed in calibrated gate experiments. These results are interpreted in terms of the fractional statistical phase acquired by a quasiparticle of the 1/3 fluid encircling the quasiparticles of the 2/5 fluid.

Keywords: Laughlin quasiparticles, interferometer, fractional statistics, fractional quantum Hall effect.
PACS: 73.43.-f, 03.65.Vf, 05.30.Pr

The elementary charged excitations (Laughlin quasiparticles) of a fractional quantum Hall (FQH) electron fluid have fractional electric charge [1,2] and therefore are expected to obey fractional statistics [3,4]. It is possible to assign definite fractional statistics to quasiparticles of certain simple FQH fluids based only on the same plausible assumptions that allow to assign their charge. Several theoretical studies pointed out that fractional statistics of Laughlin quasiparticles can be observed in variations of the Aharonov-Bohm effect [5], but the experimental evidence has been lacking.

We utilize a novel Laughlin quasiparticle interferometer, where a quasiparticle of the $f = 1/3$ FQH fluid executes a closed path around an island of the $f = 2/5$ FQH fluid, Fig. 1. The interference fringes are observed as conductance oscillations as a function of the magnetic flux through the island, that is, the Aharonov-Bohm effect. We observe the Aharonov-Bohm period $\Delta\Phi = 5h/e$, equal to excitation of ten $f = 2/5$ elementary quasiparticles of the $f = 2/5$ fluid. Such "superperiod" of $\Delta\Phi > 5h/e$ has never been reported before in any system. The corresponding $\Delta Q = 10(e/5) = 2e$ charge period is confirmed directly in calibrated backgate experiments. These results imply fractional statistics of Laughlin quasiparticles.

Samples, experimental technique, and the experimental results in the integer QH regime have been described in Ref. [6]. In the integer regime, the relevant quasiparticles are electrons of charge e and integer statistics, therefore, we can obtain an absolute calibration of the ring area and the backgate action of the interferometer device. We obtain $\Delta B_1 \approx 2.81$ mT, the *outer* ring radius $r = (h/\pi e\Delta B_1)^{1/2} \approx 685$ nm, and the backgate period $\Delta V_{BG} \approx 332$ mV, for the island charge $\Delta Q = e$.

In the fractional QH regime, we focus on the situation when an $f = 1/3$ annulus surrounds an island of the $f = 2/5$ FQH fluid, illustrated in Fig. 1. Here, as in the integer regime, we observe Aharonov-Bohm oscillations with period $\Delta B \approx 20.1$ mT, see Fig. 2(a). Fig. 2(b) shows the analogous conductance oscillations observed as a function of V_{BG}, with period $\Delta V_{BG} \approx 937$ mV. The oscillation period in this regime gives the *inner* edge ring radius of 570 nm.

We can be confident that current must flow through an $f = 1/3$ region separating the two 2D bulk $f = 2/5$ regions with Ohmic contacts because the Hall resistance in this field region is quantized to $R_{XY} = 3h/e^2$. The ratio of the conductance oscillations periods $\Delta B/\Delta V_{BG} \propto N_\Phi/N_e = 1/f$ is independent of the edge ring area and thus can be used to establish the QH filling f originating the Aharonov-Bohm oscillations. N_Φ and N_e are the number of flux quanta and electrons, respectively, within the area of the Aharonov-Bohm path. The fact that the ratios fall on a straight line forced through zero and the integers $f = 1$ and 2, Ref. [6], confirms the island filling as $f = 2/5$ at $B \approx 11.9$ T.

This "superperiod" must be imposed by the symmetry properties of the two FQH fluids [4,6]. The braiding statistics Θ of quasiparticles is analyzed as the Berry phase γ, following the analogous treatment

CP850, *Low Temperature Physics: 24th International Conference on Low Temperature Physics;*
edited by Y. Takano, S. P. Hershfield, S. O. Hill, P. J. Hirschfeld, and A. M. Goldman

of Ref. 4. The $\Delta\gamma = 2\pi$ period then contains two contributions: change of magnetic flux enclosed by the e/3 Aharonov-Bohm orbits, and the statistics term taking into account that the number of the encircled *e*/5 quasiholes is changed by ten.

The current used to measure conductance is transported by the quasiholes of the outside 1/3 fluid; therefore, we must construe that the conductance oscillations periodicity results from the 2π periodicity of the Berry phase γ of the charge $q = e/3$ Laughlin quasiparticle encircling $\Delta N = 10$ of *e*/5 quasiparticles of the $f = 2/5$ island:

$$\Delta\gamma = 2\pi[\frac{q}{h}\,\Delta\Phi + \Delta N\,\Theta] = 2\pi\ . \qquad (1)$$

This gives the relative statistics $\Theta^{1/3}_{2/5} = -1/15$ between the quasiholes of the 1/3 and the 2/5 FQH fluids.

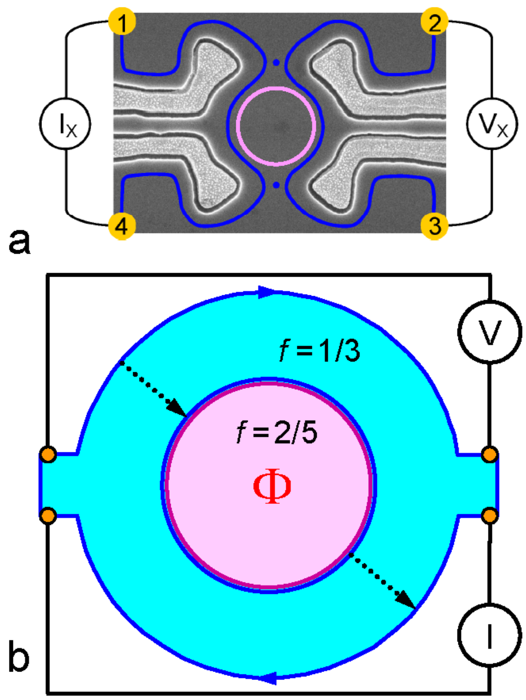

FIGURE 1. (a) Scanning electron micrographs of a typical device. Four Au/Ti front gates (FG) in shallow etch trenches define the central island of 2D electrons of lithographic radius $R = 1{,}050$ nm. The backgate (not shown) extends over the entire sample on the opposite side of the insulating GaAs substrate. (b) A QH sample with two fillings: an island of 2/5 FQH fluid is surrounded by the 1/3 fluid. The current-carrying chiral edge channels (arrowed lines) follow equipotentials at the periphery of the confined 2D electrons; tunneling paths are shown by dots. The numbered circles are the Ohmic contacts used to inject current *I* and to measure the resulting voltage *V*. The current-carrying *e*/3 quasiparticles can tunnel between the outer and the inner 1/3 edges, dotted lines. When there is no tunneling, $V = 0$; tunneling produces $V > 0$. The closed path of the *inner* 1/3 edge channel gives rise to Aharonov-Bohm oscillations in conductance as a function of the enclosed flux Φ. No current flows through the 2/5 island, but any *e*/5 quasiparticles affect the Berry phase of the encircling *e*/3 quasiparticles, thus changing the interference pattern.

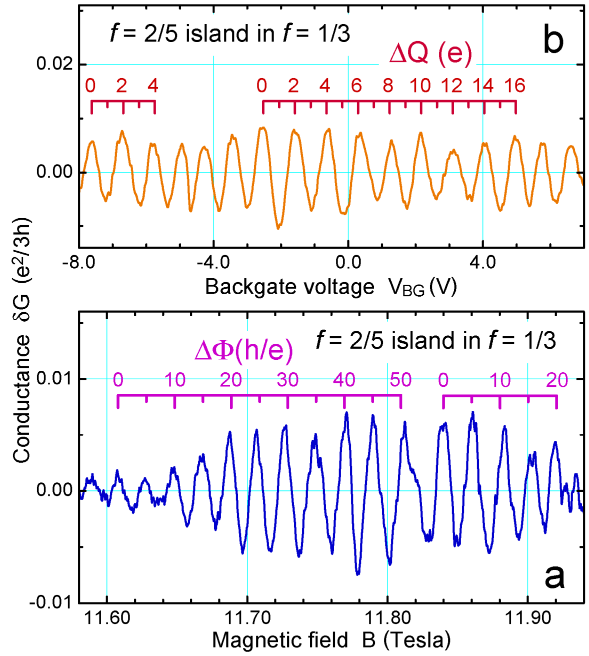

FIGURE 2. Aharonov-Bohm interference of *e*/3 Laughlin quasiparticles circling an island of $f = 2/5$ FQH fluid. (a) Magnetic flux through the island period of $\Delta\Phi = 5h/e$ corresponds to creation of ten *e*/5 quasiparticles in the island [one *h*/*e* excites two *e*/5 quasiparticles from the $f = 2/5$ FQH condensate, the total (quasiparticles + condensate) charge is fixed]. Such "superperiod" of $\Delta\Phi = 5h/e$ has never been reported before. (b) The backgate voltage period of $\Delta Q = 10(e/5) = 2e$ directly confirms that the *e*/3 quasiparticle consecutive orbits around the island are quantized by the condition requiring incremental addition of ten *e*/5 quasiparticles of the $f = 2/5$ fluid.

This work was supported in part by the National Science Foundation under Grant DMR-0303705 and NSA and ARDA through US Army Research Office under Grant DAAD19-03-1-0126.

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