Finally Fractional Oscillations

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In elementary physics courses we usually learn that all particles in the universe are either bosons or fermions. However, in two dimensions other types of particles, called anyons, can also exist. While originally this possibility, first proposed in 1977[1], was thought to be just a theoretical construct, only a few years later it was realized that the quasiparticle excitations in two-dimensional fractional quantum Hall systems should actually be anyons[2,3]. Excitement about such exotic particles greatly increased when it was proposed that one particular type of anyon, the "nonabelion" supposedly found in certain fractional quantum Hall systems, could provide a particularly robust route towards building a quantum computer[4]. Although theorists have long been convinced that anyons exist, this fact has still not been conclusively demonstrated in experiment. Now Nakamura et al.[5], writing in Nature Physics, have taken a very major step towards achieving this goal.

How can one demonstrate that particles are anyons? One needs to show that exchanging the positions of two such particles gives a quantum mechanical phase that is neither +1, as it would be for bosons, nor -1 as it would be for fermions. One promising approach is to use a mesoscopic quantum Hall Fabry-Perot interferometer[6] — a constricted quantum dot-like region of a quantum Hall bar which acts as an interference cavity. The quantum Hall edge states effectively carry charged quasiparticles in a loop around the perimeter of the cavity. By changing the size of the cavity (with voltages on gates) or by changing the magnetic field inside the loop, one should see interference oscillations of the conductance through the cavity — analogous to the Fabry-Perot fringes well known in optics. The crux of this experiment is that addition of a single quasiparticle within the center of the cavity should show a well defined fractional phase shift of the interference pattern indicative of the fractional (anyon) phase incurred when one quasiparticle traversing the perimeter encircles (i.e., exchanges twice with) another quasiparticle in the center.

Suggestive oscillations in conductance have been see in many experiments. However, these oscillations have not previously been the desired signals. There are different regimes of operation of such devices, depending on the strength of the ubiquitous Coulomb interaction[7]. These regimes are experimentally distinguished from each other by different so-called “pajama” patterns — plots of conductance as a function of both magnetic field and gate voltage. In the so-called ”Coulomb dominated” or strong interaction regime, oscillations akin to Coulmomb blockade oscillations in quantum dots can be seen in the fractional quantum Hall regime; but this is not a reflection of the fractional statistics (although it has been used to demonstrate the fractional *charge* of quasiparticles[8,9]). In the opposite limit, known as the “Aharonov-Bohm” or weak-interaction regime, oscillations *can* reflect the quantum mechanical exchange phases. Unfortunately, this regime has only been observed previously for the integer (as compared to fractional) quantum Hall effect[8] where one does not have anyons.

It is unclear why it has been so hard to observe fractional quantum Hall physics in the

Aharnonov-Bohm regime. One possibility is that the fractional edge modes are simply fragile and interference oscillations get smeared out, or dephased easily. Another possibility is that the fractional quantum Hall effect is fundamentally an interaction driven phenomnenon, so it is hard to find a window where the interaction is strong enough to form the fractional quantum Hall state, yet weak enough to not be Coulomb dominated.

The novel approach taken by Nakamura et al.[5] is to screen the Coulomb interaction in the two-dimensional electron system by placing it between two other parallel (and very nearby) electron layers. This has several possibly benefits: it reduces the Coulomb charging energy within the cavity, it changes the electrostatic potentials near the edges, and it screens some types of disorder. Whatever the reason, it is quite clear by examining the pajama pattern that this new experiment is seeing oscillations in the Aharonov-Bohm regime for fractional quantum Hall effect for the first time.

As of yet, the fractional phase indicative of anyons has still not been seen. One more step is required — one must controllably add quasiparticles to the center of the interference cavity. While this is still to be done, it seems that only a small step now remains. After over forty years, we may soon be able to declare that anyons have been discovered.

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