New bound on the precision of the fractional charge in a fractional quantum Hall fluid

Direct Comparison of Fractional and Integer Quantized Hall Resistance
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arXiv:1703.05213

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Typically, the most one can hope for in studying the properties of complex systems is approximate and qualitative agreement between theory and experiment. There are few experimentally measurable quantities in condensed matter physics whose values can be predicted exactly. Of those, the Josephson relation, $\omega = 2(e/\hbar)V$, and the quantization of the integer quantum Hall effect (IQHE), $\sigma_{xy} = ne^2/h$, are surely those that have been verified with the greatest level of precision. Indeed, they are "exact" in the sense that they are now used metrologically as the definition of $e/\hbar$ and e^2/h. Absent an independent, more accurate measure of these fundamental constants of nature, the *accuracy* of these relations cannot be tested, but their *precision* can be, and has been tested. By comparing[1] the oscillation frequency in two distinct Josephson devices, made with different superconductors, it has been established that the Josephson relation is precise to 2 parts in 10^{16}, while comparing[2] the measured values of the integer quantum Hall effect in distinct devices has confirmed the precision of the Klitzing to 3 parts in 10^{10}. These are numbers to be proud of - they refer to measurements on real samples with solder and wires attached to volt meters.

Recently, Ahler, Gotz, and Pierz (arXiv:1703.05213) have reported a notable advance in testing the precision of the fractional quantum Hall effect (FQHE) - in this case by comparing the value of the Hall voltage in a device tuned to the $\nu = 1/3$ quantum Hall state [with an expected Hall conductance $\sigma_{xy} = (1/3)\ e^2/h$] with that in an integer quantum Hall state. In this way, bounds were obtained (with 95% statistical confidence) on possible deviations of the fractional Hall conductance in this state from the theoretically expected value,

$$-3 \times 10^{-9} < \left[\left(\frac{h}{e^2} \right) \sigma_{xy} - \left(\frac{1}{3} \right) \right] < 4 \times 10^{-8}. \tag{1}$$

The numbers that enter the various relations above have unambiguous interpretations. The "2" in the Josephson relation establishes that the superconducting condensate consists of pairs of electrons - in a (in principle possible) superconductor consisting of a condensate of electron quartets, there would be a "4" in the same relation. The integer n in the IQHE indicates a level in a well defined hierarchy - notionally related to the number of filled Landau levels.

Famously, Laughlin[3] related the quantization of the QHE to the quantization of the charge of the elementary excitations of the system; indeed the existence of fractionally charged quasiparticles with fractional charge $e^\star = e/3$ in the $\nu = 1/3$ FQHE is one of the most striking aspects of the theory of the FQHE. However, in conditions in which the quantum Hall effect is observed, quasi-particles per se play no role in the quantized Hall transport - the Hall current is carried collectively by the entire fluid. Rather, applying the "Laughlin thought experiment" in reverse[4], it is simple and straightforward to prove that the existence of a quantized Hall conductance $\sigma_{xy} = e^\star e/h$ implies the existence of an excitation with a well defined quantized charge $e^\star$.

When I was a young physicist, many of the greats expressed serious doubts about whether fractional charge could ever be a sharp quantum observable. The present measurement is a direct verification[5] of the existence of a fractionally charged quasiparticle with fractional charge $e^\star = e/3$ with a precision of a few parts in 10^8!

References

[1] J-S. Tsai, A. K. Jain, and J. E. Lukens, Phys. Rev. Lett. **51**, 316 (1983).

[2] B. Jeckelmann and B. Jeanneret, Rep. Prog. Phys. **64**, 1603-1655 (2001).

[3] R. B. Laughlin, Phys. Rev. Lett. **50**, 1395-1398 (1983).

[4] For a discussion, see A. Karlhede, S. A. Kivelson, and S. Sondhi, "Quantum Hall Effect: The Article," in Correlated Electron Systems ed. by V. J. Emery, (World Scientific, Singapore, 1993).

[5] Strictly speaking, the statement is that there must exist a collection of one or more quasiparticles whose charges sum to $e^\star$; for instance, on the basis of the observation that $\sigma_{xy} = e^2/3h$ *alone*, one could equally well imagine that the quasiparticles have charge $e^\star = e/6$.