Trupmeninio krūvio sužadinimai ribotų matmenų gardelėje

Charge fractionalization in small fractional-Hall samples

Mantas Račiūnas[1], Nur Ünal[2], Egidijus Anisimovas[1], André Eckardt[2]
[1]Institute of Theoretical Physics and Astronomy, Vilnius University, Saulėtekio 3, LT-10257 Vilnius, Lithuania
[2]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Straße 38, D-01187 Dresden, Germany
mantas.raciunas@gmail.com

The discovery of fractional quantum Hall effect (FQHE) in 2D electron gas gave rise to immense interest in topological phases of matter [1]. One of the most intriguing features of FQHE state is fractionally charged excitations which embody anyonic statistics. Even though the FQHE was first observed in GaAs-GaAlAs heterojunctions, experiments in optical lattices [2] allow much more controllable study of many-body systems, therefore allowing regimes that are impossible to realise in semiconductor based experiments. Historically, FQHE comes from the field of condensed matter systems, which can be characterized by a macroscopically large number of particles, and as a consequence, numerical studies were focused only on infinite or periodical Hamiltonians in order to circumvent the limits of classical computers. Therefore, finite size systems remain mostly untouched. One can raise important questions, such as: can FQHE states be realised in minuscule lattices, containing only several sites in diameter? What additional effects would open boundary conditions introduce? What filling factor needs to be set in order to observe FQHE states? In this work we try to tackle all of these questions by numerically solving the Harper-Hofstadter Hamiltonian in the presence of bosonic onsite interactions:

$$
\begin{aligned}
H = &\sum_{n,m} (e^{im\pi/2} a^\dagger_{m,n+1} a_{m,n} + a^\dagger_{m+1,n} a_{m,n} + h.c.) \\
&+ \frac{U}{2} \sum_j \hat{n}_j (\hat{n}_j - 1) \\
&+ \sum_j V_j \hat{n}_j . \qquad (1)
\end{aligned}
$$

The first and the second terms in this equation represent the kinetic energy and interactions between bosons respectively. The last term represents a potential relief, which was used as a main probe to look for charge fractionalization. It is worth noting, that in this system charge is defined as a particle number n_j on every lattice site. The idea is to introduce localised potential defects in the form of hills or valleys and by varying their depth we expect to observe elementary excitations forming around them.

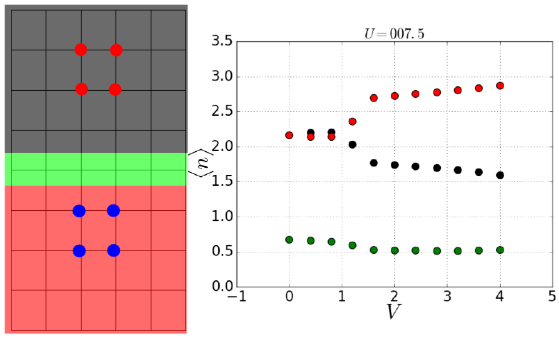

Fig 1. Charge fractionalization in 9×6 square lattice. Lattice used in simulations is depicted on the left panel. On the right plot – integrated densities $\langle n_j \rangle$ for lattice sites belonging to different shaded areas in the left panel with corresponding color. Lattice potential is set to 0 for all lattice sites, except those, marked with red ($V_j = +V/4$) or blue ($V_j = -V/4$) dots. When strength of introduced potential defects are small we see, that the sample shows almost no reaction to it as is expected from fluid-like state, however, around $V = 1.5$ there is a very steep jump (drop) in the densities around defects, indicating localisation of some charge, which reflects the formation of fractionally charged excitations with charge 1/2.

Indeed, by using this simple method we were able to observe localisation of fractional charge in several lattices with artificial magnetic flux. Various magnetic flux values, particle concentrations and geometries were evaluated. It would also be interesting to observe fractional statistics, however, proximity of the edges makes a direct observation difficult.

Keywords: Fractional quantum Hall effect, Bose-Hubbard model, optical lattice, fractional charge, Hofstadter-Harper Hamiltonian

References

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