Signatures of abelian anyon braiding

Principal Investigator Heung-Sun Sim | **Department** Physics | **Co-Investigators** - | **Hompage** http://qet.kaist.ac.kr

All known quantum particles are classified as either bosons or fermions. However, it has been theoretically predicted that in two-dimensional systems, there exist quasiparticles that belong to neither category. These quasiparticles, dubbed anyons, obey fractional (abelian or non-abelian) braiding statistics. The present study observed an essential signature – the braiding statistics – of abelian anyons in fractional quantum Hall systems by partitioning a diluted particle beam at a beam splitter and measuring the partition noise.

Background

All known quantum particles are classified as either bosons or fermions. However, it has been theoretically predicted that in two-dimensional systems, there exist quasiparticles that belong to neither category. These quasiparticles, dubbed anyons, obey fractional (abelian or non-abelian) braiding statistics [Fig. 1(a)]. The discovery of anyons (namely, the observation of their braiding properties) has been a long-standing goal in modern physics. After more than 30 years of research efforts, the first experimental signature of anyons was observed by a French research group [Bartolomei et al., Fractional statistics in anyon collisions, Science 368, 173 (2020)], and another independent signature observation was made around the same time [Nakamura et al., Nat. Phys. 16, 931 (2020)]. The French group injected two diluted electrical beams into a beam splitter in the fractional quantum Hall regime of 1/3 filling and measured the noise of the resulting electrical currents. The observed noise cannot be explained with bosons and fermions, implying the presence of a new category of particles. The French research group interpreted their result as a signal arising from the collision of two anyons, consistent with the conventional opinions held by the research community.

Description

Prof. Heung-Sun Sim noticed that the collision interpretation and the conventional view were misleading based on his theory involving a simple case of a single diluted beam injected into a beam splitter [Lee, Han, and Sim, Negative excess shot noise by anyon braiding, Phys. Rev. Lett. 123, 016803 (2019)]. His research group further developed the theory for the regime covered in the French experiment and demonstrated that the observed phenomenon arose from the braiding of abelian anyons, rather than anyon collisions [Lee and Sim, Non-Abelian anyon collider, Nat. Comm. 13, 6660 (2022)]. Prof. Sim took another step forward. To confirm his group's theory, he collaborated with the experimental group led by Prof. Moty Heilbum at the Weizmann Institute of Science. In the Weizmann experiment, a single diluted beam was injected into a beam splitter (in contrast to the two-beam injection of the French experiment) to rule out the anyon collision scenario, as sug-gested by Prof. Sim [Figs. 1b and 1c]. Prof. Sim's group analyzed the experimental data and found quantitatively good agreement with their theory of anyon braiding [Lee et al., Partitioning of diluted anyons reveals their braiding statistics, Nature 617, 277 (2023)].

Implications

The braiding mechanism discovered by Prof. Sim's group is gaining acceptance within the research community and has been termed the "time-domain braiding of anyons." In contrast to the conventional wisdom of anyon braiding occurring on a two-dimensional spatial plane, the braiding occurs with the aid of the time axis. Prof. Sim's research elevated the significance of the French experiment to the level of being the first observation of anyon braiding. Furthermore, Prof. Sim's group established a method for detecting braiding using a simple setup, as demonstrated in the Weizmann experiment. The anyons observed so far are the most stable abelian anyons. Prof. Sim's research paved the way for detecting other, more exotic (and hence more elusive) anyons, including non-abelian anyons that remain undiscovered.

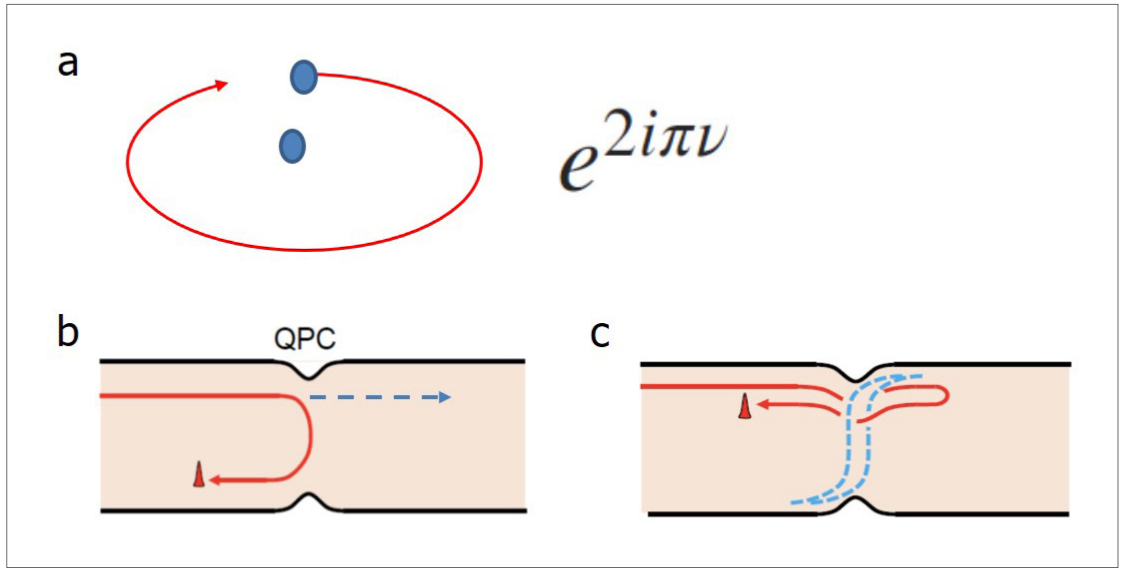

Figure 1. Braiding of abelian anyons. (a) An anyon adiabatically circulates around another on a two-dimensional plane. After one circulation, the wave functions of the two anyons gain a complex phase factor of exp($e^{2i\pi\nu}$) with a certain fraction ν (such as 1/3). This behavior is referred to as braiding. In contrast, two identical bosons or two identical fermions gain the trivial phase factor of 1 after a circulation. (b) Conventional partitioning. When a boson or a fermion is injected into a beam splitter (QPC), it is either reflected (red trajectory) or transmitted (blue dashed trajectory) at the beam splitter. (c) Time domain braiding of anyons. When an anyon is injected into a beam splitter, it exhibits a new phenomenon completely different from the conventional partitioning. Another anyon is excited at the beam splitter, and it braids the injected anyon (see the blue loop topologically linked with the red trajectory of the injected anyon). This braiding happens in the time domain and results in anomalous partitioning signals.

Research outcomes

[1] June-Young M. Lee, Changki Hong, Tomer Alkalay, Noam Schiller, Vladimir Umansky, Moty Heiblum, Yuval Oreg, and H.-S. Sim, Partitioning of diluted anyons reveals their braiding statistics, Nature 617, 277 (2023).

[2] June-Young M. Lee and H.-S. Sim, Non-Abelian anyon collider, Nature Communications, 13, 6660 (2022).

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