Dressing particles by quantum magic

The Aharonov-Bohm effect is a fascinating quantum mechanical phenomenon: Charged particles are influenced by a magnetic field even though they move in a region where the field is zero. The influence can be explained by considering the flux generated by the magnetic field, showcasing the “magic” of quantum mechanics, in particular, its non-local and topological aspects. Although this effect has been well studied, the main focus has been on a single particle neglecting interactions with the environment.

Researchers of TU Darmstadt and IST Austria have now extended previous studies by investigating the effect of a synthetic flux on a many-body system.

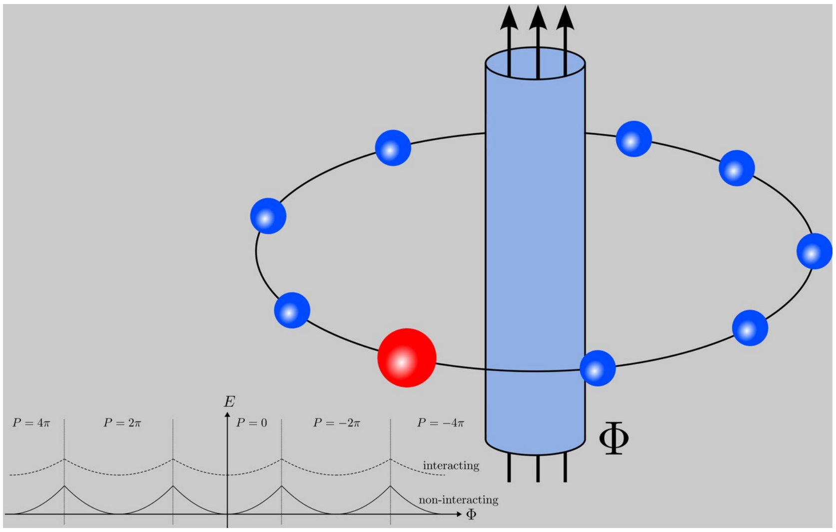

Figure 1: Sketch of the impurity system pierced by the synthetic flux. The flux ϕ can be used to influence the properties of the many-body system, such as its ground state energy E.

They simulated a system of an impurity immersed in a sea of neutral bosons confined to a one-dimensional ring pierced by a synthetic flux (see sketch). Although this may sound like a pure theoretical construct, low-dimensional systems are realized on a regular basis in experiments with ultra-cold atoms. Recent developments on the generation of synthetic gauge fields with lasers which couple to neutral atoms may bring the system under consideration in reach of experiments soon.

In their work, the researchers showed that the addition of a synthetic flux to the impurity system leads to rich physics. If the flux couples only to the impurity, it induces an impurity current which gets distributed to the bosons. Thus the movement of bosons can be controlled indirectly by the flux. The seemingly complicated many-particle distribution of currents can be understood in very simple terms: For low fluxes, the impurity current can be interpreted as the movement of an impurity with a heavier mass.

Such a “dressing” of the impurity is a well known concept in many-body physics. For example an electron moving through an ionic crystal can be described by a quasi-particle called “polaron”.

A similar picture can be used here: The effective mass depends on the interaction strength between the impurity and the bosons and the bosons themselves. The work also showed a break-down of this simple picture: For large fluxes, the current decreases more slowly, signaling the emergence of a maximal critical velocity of the impurity.

“These insights enable investigations of the emergence of many-body phenomena, like the effective mass, from few-body physics.” – says the lead author Fabian Brauneis (TU Darmstadt) – “In particular, the introduction of a synthetic flux provides a solid mathematical basis for the very definition of the effective mass in finite systems. Furthermore, our results can be useful for the creation and control of lossless currents in the ring.”

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