Study observes Luttinger liquid behavior in a quasi-2D system

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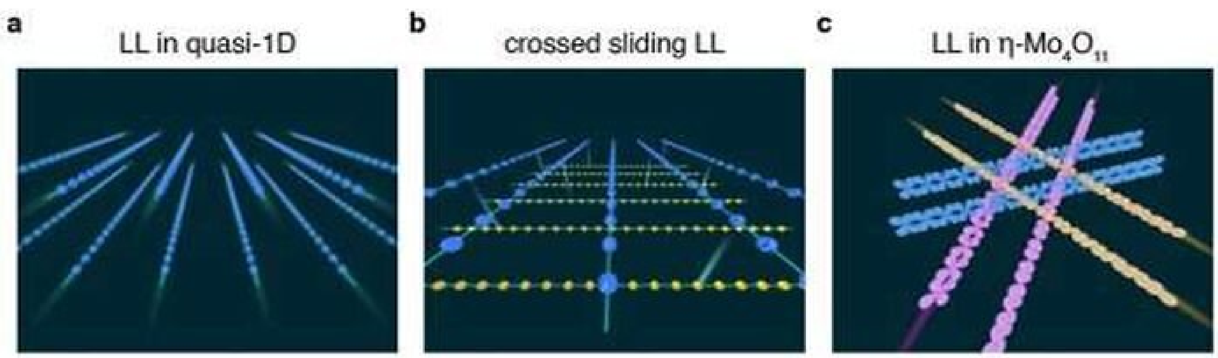

Image showing: (a) the conventional (quasi-)1D Luttinger liquid with arrays of parallel chains, (b) the theoretically proposed crossed sliding Luttinger liquid model with arrays of planar parallel chains that are spatially separated, and (c) the 2D Luttinger liquid in η-Mo4O11, where the orthogonal orbital components of electrons running along different chains guarantee the minor inter-array interactions. Credit: Du et al

Luttinger liquids are usually paramagnetic materials exhibiting non-Fermi liquid behavior, such as molybdenum oxides. These "liquids" and their fascinating properties had so far been only observed in 1D and quasi-1D compounds, such as blue bronze $A_{0.3}MoO_3$ (A= K, Rb, Tl) and purple bronze $Li_{0.9}Mo_6O_{17}$.

Researchers at Tsinghua University, ShanghaiTech University, and other institutes in China recently observed prototypical Luttinger liquid behavior in η-Mo_4O_{11},a charge-density wave material with a quasi-2D crystal structure. Their findings, published in *Nature Physics*, could pave the way for the exploration of non-Fermi liquid behavior in other 2D and 3D quantum materials.

"In our previous work, we identified the Luttinger liquid phase in the normal state of blue bronzes, which is not surprising due to its quasi-1D nature," Lexian Yang and Yulin Chen, two of the researchers who carried out the study, told Phys.org.

"We then noticed that a large family of Molybdenum oxides share common construction unit: Mo-O octahedron chains. But in some of them, such as η-Mo_4O_{11}, quasi-1D chains cross each other and weave into a quasi-2D structure."

Materials with quasi-2D structures, such as the material examined by Yang, Chen and their colleagues, have attracted considerable research attention, with physicists debating on whether they might preserve some properties of 1D materials, including Luttinger liquid behavior. Initially, the researchers did not expect to observe this behavior, thus they were very surprised when they did.

In their experiments, they used quasi-2D η-Mo_4O_{11} samples with a layered structure. The advantage of using these samples is that they can be easily cleaved to expose large and flat surfaces, facilitating their examination.

"To protect our samples from contamination, we studied the sample in an ultra-high vacuum environment by exciting electrons inside the crystals using monochromatic light," Yang and Chen explained. "We then collected these excited electrons, or photoelectrons and analyze their energy and momentum to deduced their initial status back inside the sample."

To examine their samples, Yang and his colleagues used a spectroscopic technique known as angle-resolved photoemission spectroscopy (ARPES), which allows researchers to directly visualize the electronic structure of materials. This technique can be applied to countless different types of materials, and was previously also used to examine high-temperature superconductors, topological quantum materials, and transition metal dichalcogenides.

"We showed that Luttinger liquid physics, which was previously considered as prototype 1D behavior, can be extended to quasi-2D systems," Yang and Chen said. "This extension may help us to understand other puzzling non-Fermi liquid behaviors in 2D or even 3D systems. Luttinger liquid behavior is a rare example of an exactly solvable model for interacting systems. Although it has long been regarded as the 'standard model' for 1D metals, theorists have proposed that it is related to the non-Fermi liquid behaviors in different systems such as the normal state of high-temperature cuprate superconductors."

The recent findings gathered by this team of researchers represent a significant step towards achieving a unified understanding of non-Fermi liquid behaviors in 2D and 3D systems. Their work could thus soon inspire new studies exploring Luttinger liquid behavior and other non-Fermi liquid states in other materials.

"Our future research is already underway," Yang and Chen added. "Our first step will be to explore and find more materials systems (low-dimensional Molybdenum oxides and beyond) featuring presumable Luttinger liquid. Secondly, knowing the common Luttinger liquid behavior in different materials, their similarities and differences will help unveil the physics laws underneath. Thirdly and more interestingly, the interactions between other degrees of freedom and the Luttinger liquid that could lead to long-range ordered states deserve a thorough exploration."

More information: X. Du et al, Crossed Luttinger liquid hidden in a quasi-two-dimensional material, *Nature Physics* (2022). DOI: 10.1038/s41567-022-01829-z

L. Kang et al, Band-selective Holstein polaron in Luttinger liquid material A0.3MoO3 (A = K, Rb), *Nature Communications* (2021). DOI: 10.1038/s41467-021-26078-1