Spectral evidence found for Dirac spinons in a kagome lattice antiferromagnet

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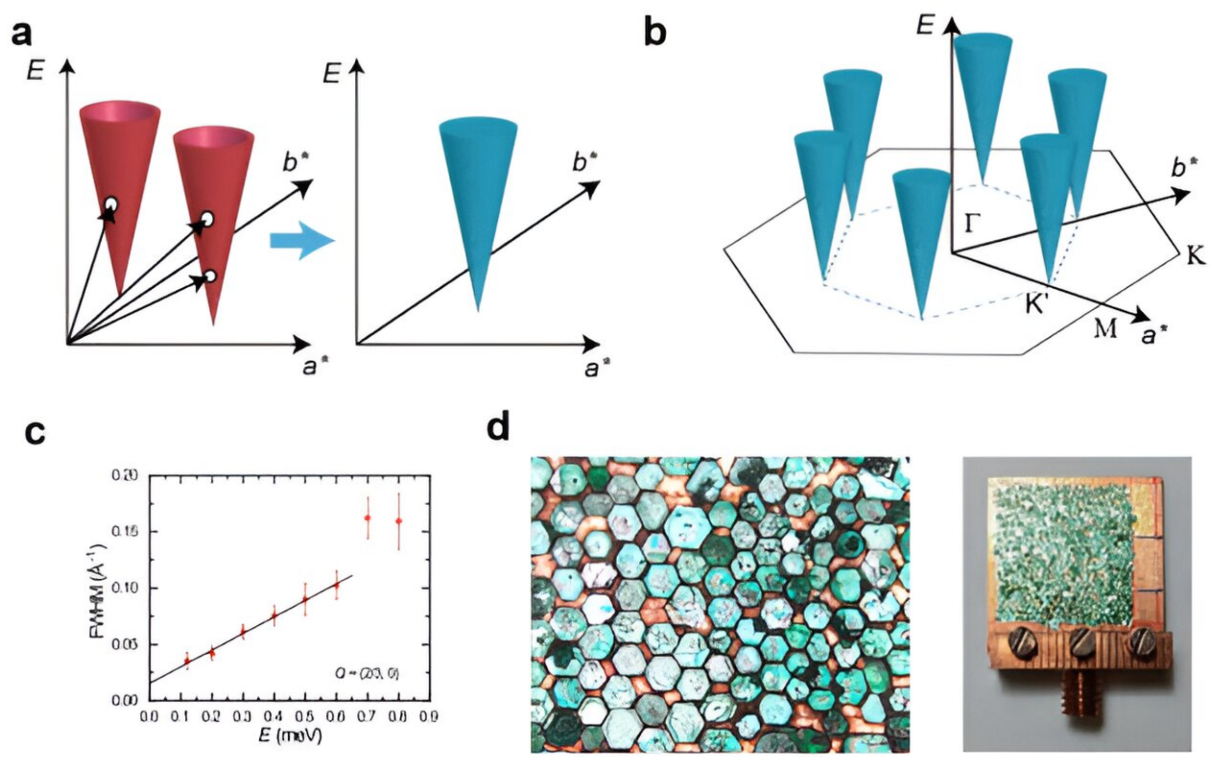


(a) Schematic diagram of the conical excitations of Dirac spinons and the conical continuum spectrum formed by two spinons. (b) Schematic diagram of the conical spin excitations in $YCu_3(OH)_6Br_2[Br_{0.33}(OD)_{0.67}]$. (c) Relationship between the half-width at half-maximum and energy. The solid line represents a linear fit. (d) A magnified image of some co-aligned crystals, and the front view of co-aligned samples on two Cu plates. Credit: *Nature Physics* (2024). DOI:

10.1038/s41567-024-02495-z

A new study, published in a recent issue of *Nature Physics*, sheds light on the long-anticipated emergence of quasiparticles, akin to the famous Dirac particles obeying the relativistic Dirac equation. These quasiparticles, known as Dirac spinons, were theorized to exist within a novel quantum state called a quantum spin liquid state.

The discovery is the result of a collaboration between theoretical physicists Dr. Chengkang Zhou and Professor Zi Yang Meng from the Department of Physics at The University of Hong Kong (HKU), along with experimentalists Zhenyuan Zeng and Professor Shiliang Li at the Institute of Physics (IOP), Chinese Academy of Sciences (CAS), and Professor Kenji Nakajima from J-PARC Center, Japan.

Quasiparticles are intriguing entities that emerge from collective behavior within materials that can be treated like a group of particles. The Dirac spinons, specifically, are expected to exhibit unique characteristics similar to Dirac particles in high-energy physics and the Dirac electrons in graphene and quantum moire materials, such as a linear dispersion relation between energy and momentum. But such spin-½ charge neutral quasiparticles have not been seen in quantum magnets before this work.

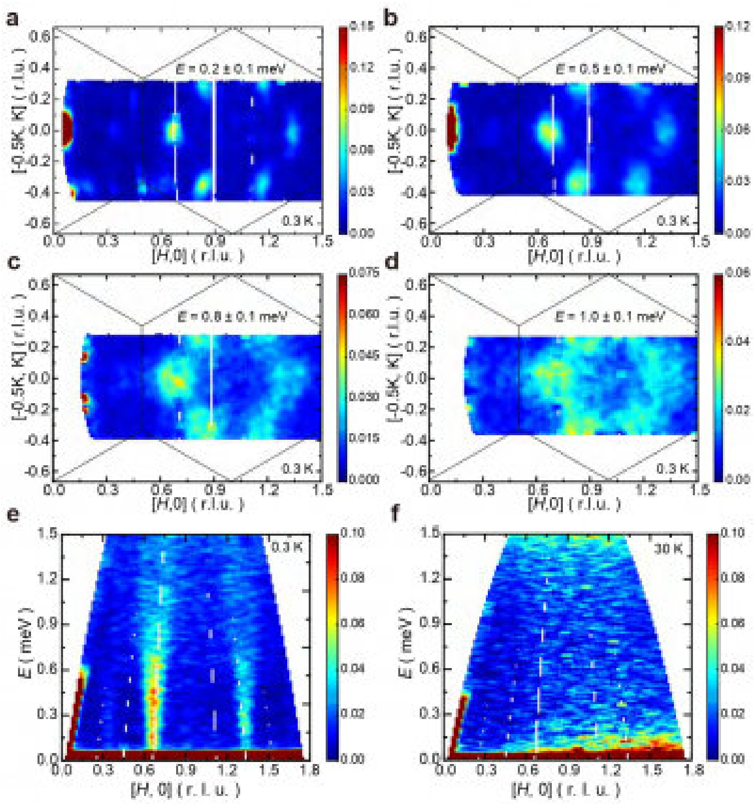
'"To find Dirac spinons in quantum magnets has been the dream of generations of condensed matter physicists; now that we have seen the evidence of them, one can start to think about the countless potential applications of such highly entangled quantum material.

"Who knows, maybe one day people will build quantum computers with it, just as people have been doing in the past half-century with silicon,'" said Professor Meng, HKU physicist and one of the corresponding authors of the paper.

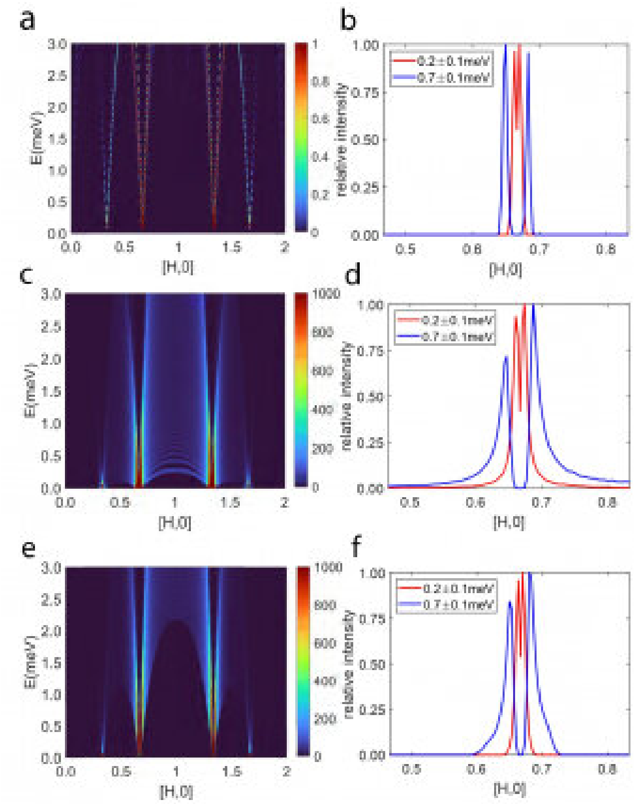
The team's investigation focused on a unique material known as YCu_3-Br, characterized by a kagome lattice structure leading to the appearance of these elusive quasiparticles.

Previous studies had hinted at the material's potential to exhibit a quantum spin liquid state, making it an ideal candidate for exploration. In order to enable the observation of spinons in YCu_3, the research team overcame numerous challenges by assembling approximately 5,000 single crystals together, meeting the requirements for conducting experiments such as inelastic neutron scattering.

Using this advanced technique, the team probed the material's spin excitations and observed intriguing conical spin continuum patterns, reminiscent of the characteristic Dirac cone. While directly detecting single spinon proved challenging due to experimental limitations, the team compared their findings with theoretical predictions, revealing distinct spectral features indicative of the presence of spinons in the material.



Spin excitations in $YCu_3(OD)_6[Br_{0.33}(OD)_{0.67}]$ measured via the neutron scattering. e,f, Intensity contour plots of the INS results as a function of E and Q along the [H, 0] direction at 0.3 K (e) and 30 K (f). Credit: *Nature Physics* (2024). DOI: 10.1038/s41567-024-02495-z



Linear spin wave prediction on the kagome lattice: a and b show the spin spectra without introducing disorder effects. c and d display the spectra with the same parameters but introduce disordered effects to fit the experimental results. e and f show the spectra with different kinds of disorder. Credit: *Nature Physics* (2024). DOI: 10.1038/s41567-024-02495-z

Finding spectral evidence of Dirac spinon excitations has always been a challenge. This discovery provides compelling evidence for the existence of a Dirac quantum spin liquid state, which can be akin to a clear cry cutting through the fog of spectral investigation on the quantum spin liquid state.

The findings not only advance our fundamental understanding of condensed matter physics but also open doors for further exploration into the properties and applications of YCu_3.

Characterized by the presence of fractional spinon excitations, the quantum spin liquid state is potentially relevant to high-temperature superconductivity and quantum information. In this state, the spins are highly entangled and remain disordered even at low temperatures.

Therefore, investigating the spectral signals arising from spinons obeying the Dirac equation would provide a broader understanding of the quantum spin liquid state of matter. Such understanding also serves as a guidepost toward its broader applications, including the exploration of high-temperature superconductivity and quantum information.

More information: Zhenyuan Zeng et al, Spectral evidence for Dirac spinons in a kagome lattice antiferromagnet, *Nature Physics* (2024). DOI: 10.1038/s41567-024-02495-z

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