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Physicists capture first thickness-dependent transitions in two-dimensional magnetic material

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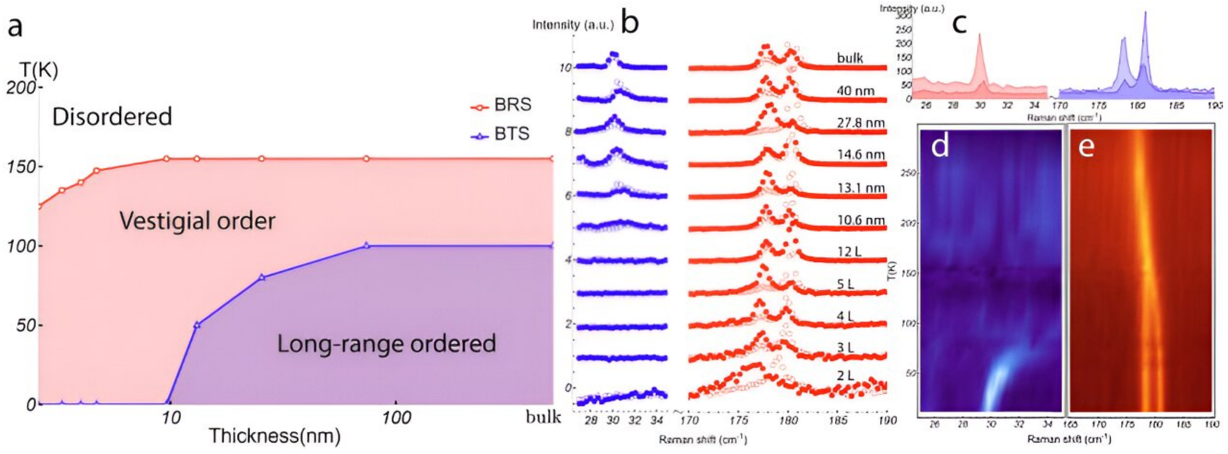

Fig. 1. Thickness dependence of signatures in optical Raman quasi-elastic scattering. a, thickness v.s. temperature phase diagram of NiPS3. b, Layer-dependent Raman spectra at T=10 K. c, linearly lairized Raman spectra measured with λ=633 nm at 10 K on bulk NiPS3. The blue (d) and red (e) areas denote the PBTS mode and PBRS mode, respectively. Credit: Adapted from *Nature Physics* (2024). DOI: 10.1038/s41567-024-02618-6

A team of physicists from The University of Hong Kong (HKU), Texas Tech University (TTH), and the University of Michigan (UMich), has made an important discovery in the study of van der Waals (vdW) magnetic materials, a special class of materials with unique electronic and magnetic properties that make them attractive for use in various applications.

Their research is the first to experimentally observe a transition in nickel phosphorus trisulfide ($NiPS_3$), a type of van der Waals material that has been studied for its potential applications in electronic devices and energy storage, from a 3-dimensional (3D) long-range order state to a 2-dimensional (2D) flat pattern vestigial order state.

They have shown how the material changes its magnetic properties as it becomes thinner, revealing new insights into how this material can be used.

This research is significant because it helps us understand how to control the magnetic properties of materials at very small scales, which could lead to advancements in technology, such as more efficient electronics, high-density data storage, and innovative computing devices that consume less energy.

Their findings have just been published in *Nature Physics*.

Unraveling Feynman's legacy: Spotlighting layered materials

"What could we do with layered structures with just the right layers?" Richard Feynman, the Nobel Prize winner in Physics in 1965, posted this intriguing question in his famous 1959 lecture, "Plenty of Room at the Bottom." This statement did not receive much attention at the time, but it was revisited in the 1990s, as it was fundamentally related to the foundations of nanotechnology.

In recent years, the emergence of van der Waals materials, such as

$NiPS_3$, has provided exciting opportunities for exploration of Feynman's question. These materials consist of layers that can be easily stacked or separated, enabling researchers to investigate their properties at varying thicknesses.

To address Feynman's question, the research team turned their attention to $NiPS_3$, which exhibits fascinating magnetic behavior when reduced to just a few layers or even a single layer. This unique property makes $NiPS_3$ an ideal candidate for studying how its magnetic characteristics evolve as its thickness changes.

In condensed matter physics, one of the key ways to study materials is to understand how they transition between different phases or states as their properties, like temperature or thickness change. These transitions often involve changes in the material's symmetry, a concept known as symmetry breaking.

In the case of $NiPS_3$, the researchers observed an intermediate symmetry breaking which leads to a vestigial order. Just as the term "vestigial" refers to the retention of certain traits during the process of evolution, the vestigial order here can also be viewed as the retention during the process of symmetry breaking.

This happens when the primary magnetic long-range order state melts or breaks down into a simpler form, in the $NiPS_3$ case, a 2D vestigial order state (known as Z_3 Potts-nematicity), as the material is thinned. Unlike conventional symmetry breaking, which involves the breaking of all symmetries, vestigial order only involves the breaking of some symmetries.

While there are numerous examples from a theoretical standpoint, experimental realizations of vestigial order have remained challenging. However, the investigation of this 2D magnetic material has shed the first light on this issue, demonstrating that such a phenomenon can be observed through dimension crossover.

When theory and computation meet experiments

To capture the emergence of the vestigial order, the research team studied $NiPS_3$ and utilized nitrogen-vacancy (NV) spin relaxometry and optical Raman quasi-elastic scattering to characterize the melting process in the primary order and the emergence of the vestigial order as the thickness changed (see figure 1).

In order to better understand the experimental findings of the dimensional crossover in $NiPS_3$, the team also performed large-scale Monte Carlo simulations to visualize the magnetic phase for bilayer $NiPS_3$ (see figure 2).

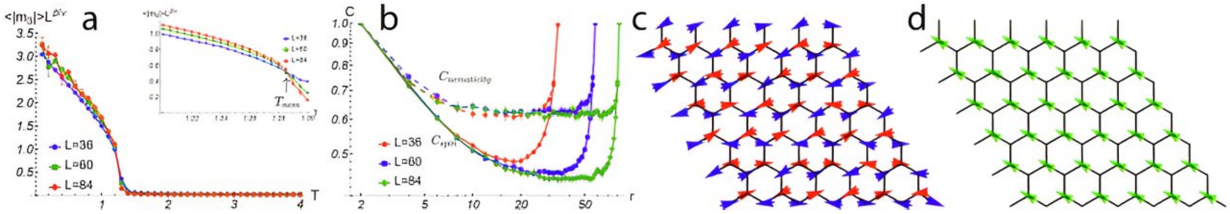

Fig. 2. Monte Carlo calculations of the magnetic state in 2L $NiPS_3$. a, Temperature dependence of the scaled Potts-nematic order parameter (⟨|m⟩|⟩). Inset: Zoom-in around nematic phase transition temperature TN, 2L=1.285J1. b, Correlation of Potts-nematicity (Cnematicity) and spin (Cspin) at a temperature T=1.25|J1|

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