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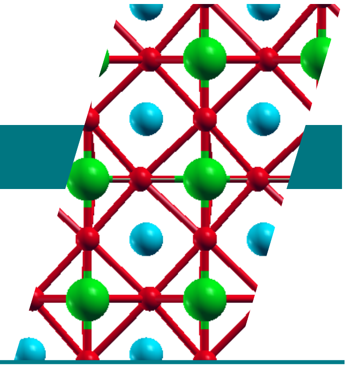
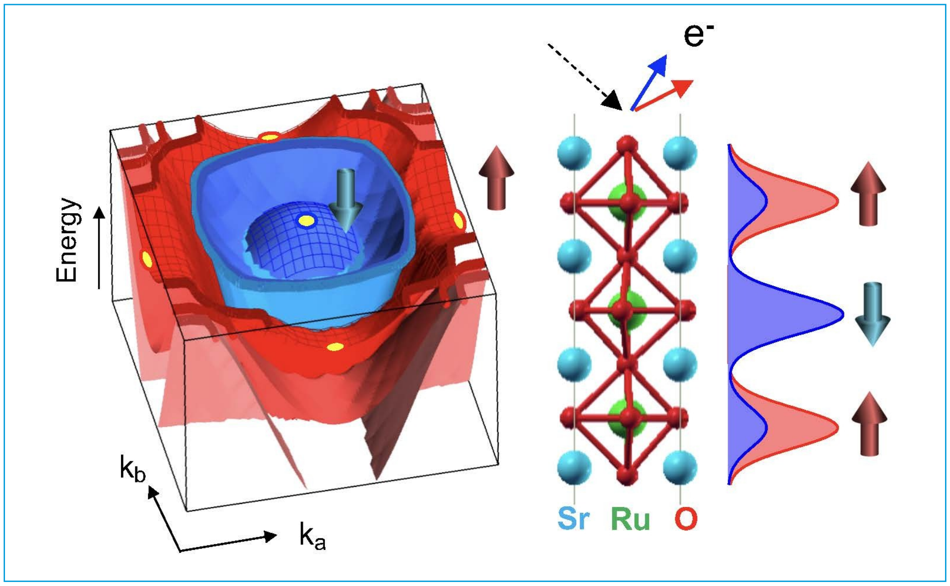


MATERIALS SCIENCES

Pinpointing Magnetic Mysteries and Mechanisms in a Layered Perovskite



Left: Schematic representation of the spin-polarized electronic band structure of triple-layer strontium ruthenate ($Sr_4Ru_3O_{10}$). Select locations (yellow points) along the momentum (*k*-) axes identify two different van Hove singularity points with opposite electron spins. Right: Schematic of the different relative spatial locations of the van Hove singularities in the central (down) and outer layers (up) of the structure.

Scientific Achievement

Researchers revealed how electrons with different spins behave in distinct layers of a three-layer magnetic material, helping to explain its unusual magnetic behavior.

Significance and Impact

The results deepen the field's understanding of how magnetism emerges in layered materials, which are important for future magnetic technologies and quantum electronic devices.

Architecture for 2D magnetism

The perovskite strontium ruthenate family ($Sr_{n+1}Ru_nO_{3n+1}$) consists of layered materials that stack into different configurations. When *n* is large, the compound has a three-dimensional (3D) structure. For smaller *n*, the material forms quasi-two-dimensional (2D) *n*-layer slabs of RuO_6 octahedra.

While the 3D compound ($SrRuO_3$) is a conventional ferromagnet, the 2D single-layer version (Sr_2RuO_4) is a superconductor. Between these extremes lies $Sr_4Ru_3O_{10}$, a triple-layer compound that combines the desirable properties of ferromagnetism and two-dimensionality, a current high interest research area.

This structure also possesses mysterious 'metamagnetic' behavior where a magnetic field can trigger an abrupt change in its in-plane magnetism.

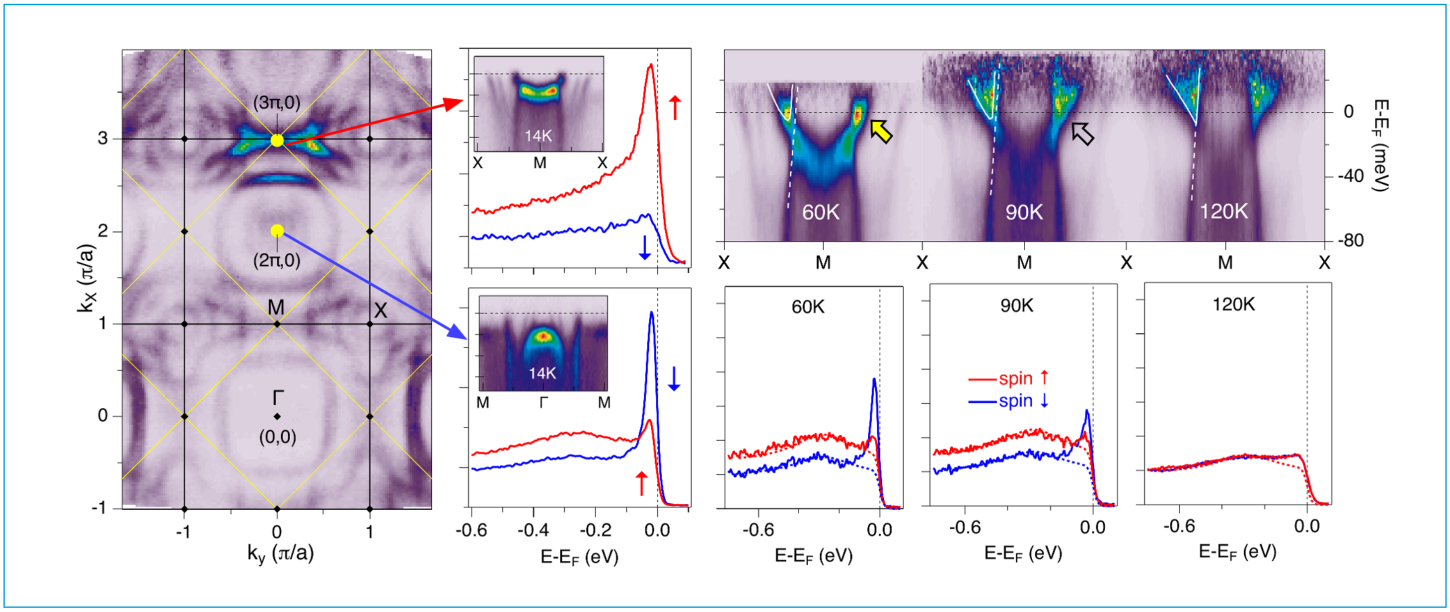
Revealing the magnetic architecture

An early experimental study of the $Sr_4Ru_3O_{10}$ band structure using angle-resolved photoemission (ARPES) measurements inspired a collaboration with theorists within the African School for Electronic Structure Methods and Applications. The theoretical calculations, which predicted strong spin-polarization of bands in the ferromagnetic phase, led to an experimental collaboration at the Advanced Light Source (ALS).

The team first performed a broad ARPES survey of the photoemission intensities on $Sr_4Ru_3O_{10}$ samples at ALS Beamline 4.0.3 to determine the optimized angles and photon energies, which were then used for the spin-resolved measurements at Beamline 10.0.1. The spin-resolved ARPES instrument is equipped with 3D, very-low-energy electron diffraction (VLEED) spin detectors, enabling the collection of electrons with different spin components.

Electron traffic jams

The ARPES data revealed two separate narrow electronic bands with opposite spin orientation. The sharp spectral peaks,



Fermi surface map (left) showing the locations of spin-resolved ARPES measurements (middle) of two different narrow band van Hove singularity (vHS) points with opposite spin and strong temperature-dependent amplitude reduction and loss of ferromagnetic spin-polarization above T_c=105 K (lower right). A spin-down band (dashed line, upper right) intersects the spin-up vHS band creating smaller mini-vHS points (arrows) only when the band-crossing interaction is strong below 60 K.

called van Hove singularities (vHS), indicate where an electron 'traffic jam' develops due to a high concentration of electron states. The comparison of the ARPES data to theoretical calculations identified the electron orbitals of the two vHS points. Their different orbital symmetries then determine that the points are spatially separated.

Identifying the tipping point

At low temperature, the spin-up big vHS band is broken into smaller low-energy scale mini-vHS points. These points are sensitive to external magnetic fields and mark the ‘tipping point’ for the abrupt metamagnetic transition. This tipping point provides the ‘switch’ that triggers an abrupt change in the compound’s in-plane magnetism. The research team determined that the mini-vHS ‘trigger’ points only occur in the outer layers of the compound and that they disappear above 60 K, consistent with the temperature-dependent evolution of the magnetic field-induced 'jump'.

The ability to manipulate vHS energies by magnetic fields, temperature, or other perturbations opens new prospects to control magnetism strategically. The detailed microscopic understanding of this effect in $Sr_4Ru_3O_{10}$ may benefit future attempts to design materials with abrupt switchable properties that could be used in quantum technologies for developing next-generation magnetic devices.

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