Overcoming Frustration

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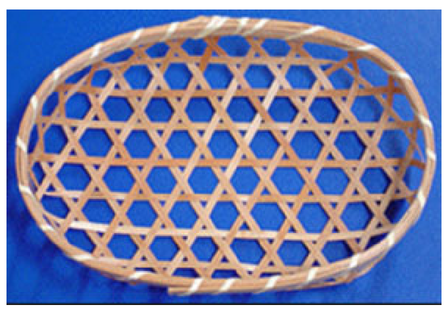
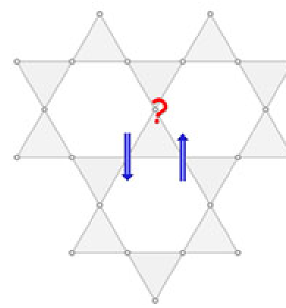
UT's physicists have navigated their way through a frustrating system to find exotic physics in a new family of compounds. The results are both the first experimental realization and first theoretical investigation of the tripod kagome lattice (TKL), a structure that had not been studied previously but could open a new field of research in condensed matter physics and materials science.

Physics Graduate Student Zhiling Dun is the lead author on a recent *Physical Review Letters (PRL)* paper outlining the work, which was selected as an Editors' Suggestion. This designation is reserved for a small number of papers each week and encourages readers to study fields beyond their usual interests. With findings about structural and magnetic properties in materials, this research easily transcends scientific boundaries.

While the TKL structure was actually discovered by chemists in 2014, the paper lays out how Dun and his colleagues (including **Assistant Professor Haidong Zhou (http://www.phys.utk.edu/faculty/faculty-zhou.html)**, his research advisor) synthesized new compounds with the tripod kagome lattice to emphasize the importance of the physics. The terminology, however, has somewhat less scientific roots.



Kagome Basket



Kagome Lattice

Dun explained that "Kagome is a traditional Japanese woven bamboo pattern. Its name is composed from the words kago, meaning 'basket,' and me, meaning 'eye(s),' referring to the pattern of holes in a woven basket."

Physicists adapted the name to describe a frustrated lattice made of corner shared triangles. A frustrated lattice describes a particular structure where localized electron spins, interacting through competing exchange interactions, cannot be simultaneously satisfied. Spin is an intrinsic property of electrons. When restricted by lattices as a localized moment, it usually can point in binary directions (Ising), within a rotation plane (*XY*), or in three-dimensional space (Heisenberg). In a frustrated model, where localized spins are strongly coupled, there is more than one way of spin arrangements that minimizes the energy of the system. The system is thus "frustrated," having a hard time achieving long ranged spin ordering.

"The kagome lattice is one of the most geometrically frustrated lattices," Dun said.

Still, kagome lattice magnets (KLM) are excellent candidates for quantum spin states, and theoretical predictions for these materials indicate they could have exciting magnetic properties.

"However," Dun added, "nature simply does not like the kagome lattice. Experimentally, it is difficult to synthesize a KLM in the lab. This reality leads to a large gap between the theoretical and experimental studies."

This is what makes the *PRL* work so informative. The researchers devised a Hamiltonian function based on a kagome lattice model. They combined different experimental probes with theory to measure the magnetic properties of compounds comprising magnesium, antimony, oxygen, and one of three rare earth (RE) elements: gadolinium, dysprosium, and erbium. Each of the three RE elements represents a different spin type. The findings resulted in three different exotic states depending on which element was used. The gadolinium compound was a 120 degree spin ordered state, demonstrating the importance of dipole interactions. The dysprosium system was a rare example of a kagome "spin ice" state—a shorted ranged ordered magnet with frustrated interactions. In the erbium compound, researchers observed a possible Kosterlitz-Thouless transition, which is associated with strong quantum fluctuations.

"To our knowledge, none of these physics has ever been experimentally realized before in a KLM," Dun said.

Beyond that, they can use the fitting parameters from their experimental data for theoretical calculations to better understand the magnetic ground states observed.

"The letter we published provides the first experimental realization and theoretical investigation of the tripod kagome lattice system," Dun said. "Even for the three systems we studied, the physics is still not confirmed nor fully understood yet. Further experimental measurements are needed."

There are interesting challenges and opportunities for studying this particular structure. The tripod-like axes distinguishes the TKL from other kagome lattice materials studied previously. Further, this new compounds family could give rise to more exotic physics given the wide range of spin sets in rare elements.

"The future exploration of the whole TKL family is expected to open a new field in condensed matter physics and materials science studies for coming years, such as the pyrochlore did during the last two decades," Dun said.

Dun has had an impressive tenure as a graduate student at UT. This year he won the department's Fowler-Marion Award, designated for an outstanding graduate student. In 2015 he was recognized with a Chancellor's Citation for Extraordinary Professional Promise. He has published 21 papers, appearing as first author on six of them, and anticipates completing his Ph.D. in 2017.

Read the paper [Magnetic Ground States of the Rare-Earth Tripod Kagome Lattice $Mg_2RE_3Sb_3O_{14}$ (RE=Gd,Dy,Er)] online: **http://journals.aps.org/prl/abstract/10.1103/PhysRevLett.116.157201 (http://journals.aps.org/prl/abstract/10.1103/PhysRevLett.116.157201)**