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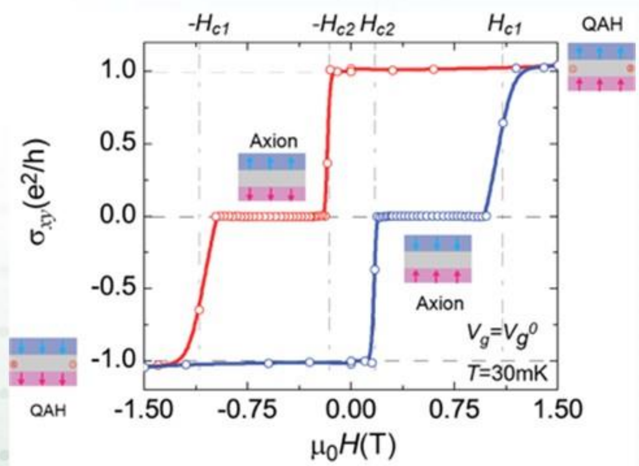
Observation of axion physics in condensed matter

D. Xiao, J. Jiang, J-H. Shin, F. Wang, Y-F. Zhao, C-X. Liu, M.H.W. Chan, Ni. Samarth, C-Z. Chang (Penn State); W. Wang, W. Wu (Rutgers)

The strongly spin-momentum coupled electronic states on the surfaces of topological insulators (TIs) exist because of time-reversal symmetry. The theoretical description of these states is fundamentally analogous to a picture used to describe particles known as 'axions' theoretically postulated to exist in Nature but never observed. Demonstrating and understanding this conceptual analogy is important for gaining new insights into how our universe works. By interfacing the two opposite surfaces of a TI thin film with different magnetic materials and measuring the magnetic field dependence of the electrical conductance, we show that the 'axion' analogy is robust and leads to a new phase of matter known as an 'axion insulator.'



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DMR DIVISION OF MATERIALS RESEARCH
DIRECTORATE FOR MATHEMATICAL AND PHYSICAL SCIENCES

What Has Been Achieved: The strongly spin-momentum coupled electronic states in topological insulators (TI) are created by a combination of spin-orbit coupling and time-reversal symmetry. The surface conductance associated with these states is expected to be quantized and has a mathematical description identical to that used for fundamental particles known as 'axions'. The axion description can be robustly proven by interfacing the two opposite surfaces of a TI thin film with magnetic moments that can be independently reoriented with respect to each other. We have used this property to demonstrate axion physics by measuring the Hall effect and electric resistance of such a TI heterostructure. When the magnetization on the opposite surfaces is in the same direction, the Hall conductance is quantized to e^2/h, where e is electron charge and h is Planck's constant, while the electrical conductivity is zero. This is known as the quantum anomalous Hall (QAH) insulator. When the magnetizations are oppositely oriented, the Hall and electrical conductivity both vanish. This is the 'axion insulator.'

Importance of Achievement: Our results provide a robust model system for studying fundamental concepts in physics that cut across subfields, including condensed matter, field theory and particle physics.

Unique Features of the MIP That Enabled Project: MBE growth of high quality topological insulator thin films on GaAs substrates.

Publications:

Xiao, D., Jiang, J., Shin, J.-H., Wang, W., Wang, F., Zhao, Y.-F., Liu, C.-X., Wu, W., Chan, M. H. W., Samarth, N., Chang C.-Z.

(2018) Room-temperature spin-orbit torque switching induced by a topological insulator. Phys. Rev. Lett. 056801.