The Advanced Photon Source

Under Pressure, a "Squishy" Compound Reacts in Remarkable Ways

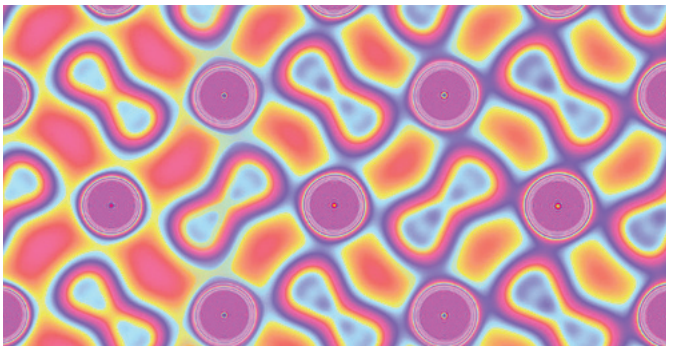
Remarkable things happen when a "squishy" compound of manganese and sulfide (MnS_2) is compressed in a diamond anvil cell, say researchers from the University of Rochester and the University of Nevada, Las Vegas (UNLV). This material was observed to go from insulator to metal and back again—a new transition phenomenon reported by Rochester and Las Vegas researchers using x-ray diffraction measurements conducted at the High Pressure (HP) CAT 16-ID-B x-ray beamline at the U.S. Department of Energy's APS.

"This is a new type of charge transfer mechanism, and so from a science community point of view this is very, very exciting. We are showing remarkable physical transformations over a very, very short range of parameters, in this case pressure," said Ashkan Salamat, associate professor of physics at UNLV and co-author of the paper flagged as an editor's choice in *Physical Review Letters*.

"Metals usually remain metals; it is highly unlikely that they can then be changed back to an insulator," said co-author Ranga Dias, assistant professor at Rochester. "The fact that this material goes from an insulator to a metal and back to an insulator is very rare."

Moreover, the transitions are accompanied by unprecedented decreases in resistance and volume across an extremely narrow range of pressure change—all occurring at about 80° F. The relatively low temperature enhances the chances that the metal transition process might eventually be harnessed for technology.

In previous work, the collaboration set new benchmarks toward achieving superconductivity at room temperatures. A common denominator of their work is exploring the bizarre ways transition metals and other materials behave when they are paired with sulfides, and then compressed. "There's something very intriguing about how sulfur behaves when it is attached to other elements. This has led to some remarkable breakthroughs" Salamat said.



As a compound of manganese sulfide is compressed in a diamond anvil cell, it undergoes dramatic transitions. In this illustration, the interaction between the manganese (Mn) atomic ions (purple circles) and disulfur (S2) molecular ions (figure 8s) increases from left to right until the overlap is significant enough to make the system metallic. (Illustration courtesy of Dean Smith, Argonne National Lab)

Underlying the transitions described here are the way the spin states (angular momentum) of individual electrons interact as pressure is applied. When MnS_2 is in its normal insulator state, electrons are primarily in unpaired, high spin orbitals, causing atoms to actively bounce back and forth. This results in the material having higher resistance to an electrical charge because there is less free space for individual electron trying to pass through the material.

As pressure is applied and the material is compressed toward a metallic state, the electron orbitals start to interact and pairs of electrons link up as one. Low resistance is maintained even in the final phase when the MnS_2 reverts to an insulator because the electrons remain in a low spin state.

The recent work done by Dias, Salamat, and collaborators continues to show that there are many surprises yet to be discovered when materials are compressed to extreme densities, and the result is another great example where the bright synchrotron beams are critical in shedding light on new phenomena.

See: Dylan Durkee et al., "Colossal Density-Driven Resistance Response in the Negative Charge Transfer Insulator MnS_2," Phys. Rev. Lett. **127**, 016401 (2021). DOI: 10.1103/PhysRevLett.127.016401

This material is based upon work supported by the National Science Foundation (NSF) Division of Materials Research under Grant No. 1904694. N. D.-G., E. S., and R. P. D. were supported by NSF Grant No. DMR-1809649; U.S. Department of Energy (DOE) Stockpile Stewardship Academic Alliance Program Grant No. DE-NA0003898; and U.S. DOE Office of Science, Fusion Energy Sciences under Award No. DE-SC0020340. S. A. J. K. was supported by Contract No. ANR-15-IDEX-0003. HPCAT-XSD operations are supported by the DOE-National Nuclear Security Administration's Office of Experimental Sciences. The Advanced Photon Source is a U.S. DOE Office of Science User Facility operated for the DOE Office of Science by Argonne National Laboratory under Contract No. DEAC02-06CH11357.

Call for APS General-User Proposals

The Advanced Photon Source is open to experimenters who can benefit from the facility's high-brightness hard x-ray beams.
General-user proposals for beam time during Run 2022-1 are due by October 29, 2021.
Information on access to beam time at the APS is at http://www.aps.anl.gov/Users/apply_for_beamtime.html or contact Dr. Dennis Mills, DMM@aps.anl.gov, 630/252-5680.

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The Advanced Photon Source is a U.S. DOE Office of Science User Facility operated for the DOE Office of Science by Argonne National Laboratory under Contract No. DE-AC02-06CH11357

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