Under pressure, 'squishy' compound reacts in remarkable ways

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As a compound of manganese sulfide is compressed in a diamond anvil, it undergoes dramatic transitions. In this illustration, the interaction between the manganese (Mn) atomic ions (purple circles) and disulfur (S$_2$) molecular ions (figure 8s) increases from left to right until the overlap is significant enough to make the system metallic. Credit: Dean Smith, Argonne National Lab

Remarkable things happen when a "squishy" compound of manganese and sulfide (MnS$_2$) is compressed in a diamond anvil, say researchers from the University of Rochester and the University of Nevada, Las Vegas (UNLV).

"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," says Ashkan Salamat, associate professor of physics at UNLV.

For example, as the pressure increases, MnS$_2$, a soft insulator, transitions into a metallic state and then into an insulator again, the researchers describe in a 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," says Ranga Dias, assistant professor of mechanical engineering and of physics and astronomy 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 degrees Fahrenheit. The relatively low temperature enhances the chances that the metal transition process might eventually be harnessed for technology, Salamat says.

"The new phenomena we are reporting is a fundamental example of responses under high pressure—and will find a place in physics textbooks," Salamat says. "There's something very intriguing about how sulfur behaves when it is attached to other elements. This has led to some remarkable breakthroughs."

The breakthroughs achieved by the Dias and Salamat labs have involved compressing mere picoliters of material—about the size of a single inkjet particle.

**Spin and pressure underlie dramatic metal transition**

Underlying the transitions described in this paper are the way the spin states (angular momentum) of
individual electrons interact as pressure is applied, Dias and Salamat explain.

This opens up more space for individual electrons to move through the material—so much so that resistance drops dramatically by 8 orders of magnitude, as pressure is increased from 3 gigapascals (435,000 psi) to 10 gigapascals. This is a relative "nudge" compared to the 182 to 268 gigapascals required for superconducting materials.

"Given the small range of pressure involved, a drop in resistance of this magnitude is really enormous," Dias says.

Low resistance is maintained even in the final phase—when the MnS\textsubscript{2} reverts to an insulator—because the electrons remain in a "low spin" state.

**Basic materials science, future technological advances**

As often occurs with new discoveries in basic science, the possible applications have yet to be explored.

However, Salamat says, a transition metal which, with a relatively small amount of strain, can jump from one state to another—at room temperature, no less—is likely to be useful.

"You could imagine having a logic switch or writing hard disk, where a very, very small permutation in strain or voltage could make something jump from one electronic state to another. New versions of flash memory, or solid state memory, could permutate and take on a new approach using these types of materials," Salamat says.

"You can do quite aggressive maneuvers to drive these materials at 300 kelvin, making them potentially useful for technology."

Lead author Dylan Durkee, a former undergraduate researcher in the Salamat lab, is now working as a graduate student with Dias. Other coauthors include Nathan Dasenbrock-Gammon and Elliot Snider at Rochester; Keith Lawler, Alexander...
Smith, and Christian Childs at UNLV; Dean Smith at Argonne National Laboratory, and Simon A.J. Kinder at University of Bourgogne.


Provided by University of Rochester


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