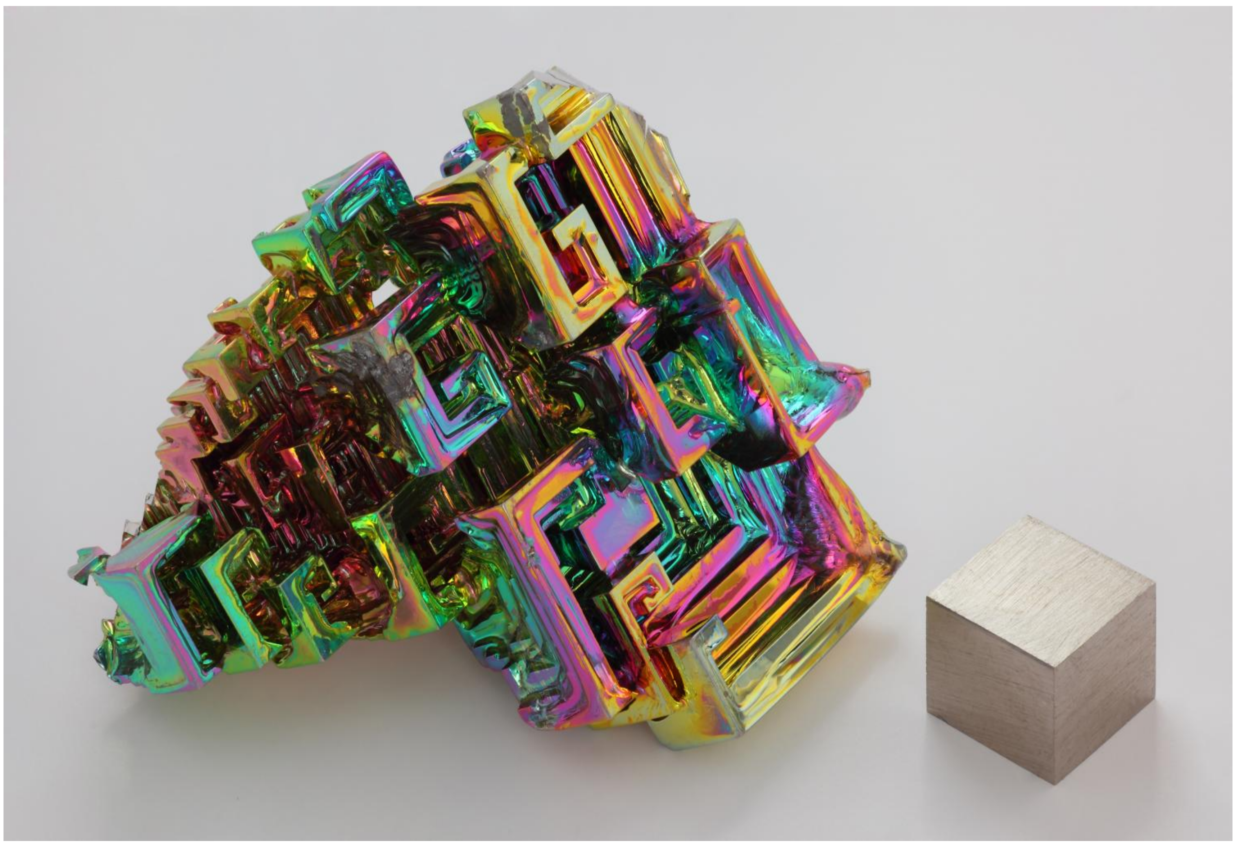
Discovery of bismuth superconductivity at extremely low temperature jeopardizes theory

December 2 2016, by Bob Yirka



Artificially grown bismuth crystal illustrating the stairstep crystal structure, with a 1 cm3 cube of bismuth metal. Credit: Wikipedia

(Phys.org)—A team of researchers at the Tata Institute of Fundamental

Research in India has found that cooling a sample of bismuth to 0.00053 Kelvin caused the material to become a superconductor, putting at risk a decades-old theory regarding how superconductivity works. In their paper published in the journal *Science*, the team describes their cooling and testing approach and why they believe what they found will require physicists to rethink theoretical work that describes the conditions under which a metal can become superconductive.

After it was discovered that some metals can be superconductive under certain conditions (back in 1911), scientists have been hard at work trying to understand how they work so that they can take advantage of them. Much progress has been made—superconductivity is now commonly used in some devices such as particle accelerators—but the ultimate goal has yet to be reached—finding a metal that is superconductive at room temperature. In this new effort, the researchers looked at bismuth—a brittle reddish-gray metal that had been dismissed as a possible superconductor because it has such a small carrier density (one mobile electron is shared by 100,000 atoms).

To test the metal, the team drilled holes in a silver rod and then pushed bismuth crystals into them. They then covered the rod with a magnetic shield that was used to pass a magnetic field over the bismuth samples. Sensors in the shield were sensitive enough to pick up magnetic field changes down to 10^{-18} Tesla. The team then chilled the construct they had made, watching for the point at which the magnetic field around the bismuth samples increased (an indicator of the Meissner effect)—that point arrived at 0.00053 Kelvin, revealing that the metal could be caused to be a superconductor when made cold enough.

The finding by the team has shed doubt on the reliability of the Bardeen-Cooper-Schrieffer theory, because the metal does not have enough electrons to allow for partnering up—the means by which most semiconductors operate without resistance. It also now represents the lowest carrier density superconductor. The work by the team also demonstrates that despite a significant amount of effort put into studying superconductivity, it is still not very well understood.

More information: O. Prakash et al. Evidence for bulk superconductivity in pure bismuth single crystals at ambient pressure, *Science* (2016). DOI: 10.1126/science.aaf8227

Abstract
At ambient pressure, bulk rhombohedral bismuth (Bi) is a semimetal that remains in the normal state down to at least 10 mK. The superconductivity (SC) in bulk Bi is thought to be unlikely because of the extremely low carrier density. We observe bulk SC in pure Bi single crystals below 0.53 mK under ambient pressure with an estimated critical magnetic field of 5.2 μT at 0 K. SC in Bi cannot be explained by the conventional Bardeen-Cooper-Schrieffer theory because its adiabatic approximation does not hold true for Bi. Future theoretical work will be needed to understand SC in the non-adiabatic limit in systems with low-carrier density and unusual band structure, such as Bi.