An international team led by Princeton University scientists has discovered an elusive massless particle first theorized 85 years ago: the Weyl fermion. It was detected as an emergent quasiparticle in synthetic crystals of the semimetal, tantalum arsenide (TaAs). Using angle-resolved photoemission spectroscopy (ARPES), the researchers studied the surface and bulk band structure of TaAs. The results exhibit the features—cones, nodes, and arcs—that establish the presence of Weyl fermions. These exotic particles, if applied to next-generation electronics, could allow for the nearly free and efficient flow of electricity, and thus greater power, in devices such as computers. More generally, the work paves the way for the realization of many fascinating topological quantum phenomena.

Weyl fermions were proposed by the mathematician and physicist Hermann Weyl in 1929 as an alternative to Einstein’s theory of relativity. Although that application never panned out, the characteristics of his theoretical particle intrigued physicists for nearly a century. Unlike electrons, Weyl fermions are massless and possess a high degree of mobility. They also possess a form of chirality in which their spin is either in the same direction as motion (right-handed) or in the opposite direction (left-handed). Their basic nature means that Weyl fermions move very quickly on the surface of the crystal with no backscattering, which hinders efficiency and generates heat in normal electronic materials.

According to established theory, a Weyl semimetal state could only arise in a crystal where either time-reversal symmetry or inversion symmetry is broken. Initially, the team researched hundreds of crystal structures and simulated dozens of likely structures. They published an earlier paper theorizing that Weyl fermions could exist in a class of materials composed of a transition metal (e.g. Ta or Nb) and a Group 15 element (e.g. As or P). They synthesized asymmetrical TaAs crystals and brought them to the ALS (Beamlines 4.0.3, 10.0.1, and 12.0.1) as well as other synchrotron light sources (Stanford Synchrotron Radiation Lightsource, Diamond Light Source,


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Stone, bronze, iron, silicon: in ages past and present, materials have had the power to shape civilization. Now, some believe we are on the verge of a golden age of materials science, in which new materials are rationally designed rather than discovered by accident or through painstaking trial and error. Converging advances in supercomputing, nanofabrication, and materials characterization (at facilities such as the ALS) are enabling new materials specifically designed for artificial photosynthesis, for example, or for processing more information in less space at lower power.

In this work, Xu et al. sifted through hundreds of materials with the desired structural characteristics, identified the ones likely to be semimetals or narrow-bandgap semiconductors, and performed systematic calculations of their band structures. “The nature of this research and how it emerged is really different and more exciting than most of other work we have done before,” Xu said. “Usually, theorists tell us that some compound might show some new or interesting properties, then we as experimentalists grow that sample and perform experiments to test the prediction. In this case, we came up with the theoretical prediction ourselves and then performed the experiments. This makes the final success even more exciting and satisfying than before.”

Point, it is a Weyl semimetal, and the point is called a Weyl node.

Superimposing the SX-ARPES bulk data containing the Weyl nodes onto the VUV-ARPES data containing the surface Fermi arcs to scale, the researchers noted that all the arc terminations and projected Weyl nodes match within the experimental resolution. Because the SX-ARPES bulk data and the VUV-ARPES surface data are completely independent measurements obtained at two different beamlines, the fact that they match well provides another piece of evidence of the topological nature (the surface–bulk correspondence) of the Weyl semimetal state in TaAs.

Although practical technologies are still a long way off, publications about Weyl fermions have increased rapidly since the discovery was reported, signifying the opening of an exciting new frontier in condensed matter physics. “The physics of the Weyl fermion are so strange,” said M. Zahid Hasan, the Princeton physics professor who led the research team, “there could be many things that arise from this particle that we’re just not capable of imagining now.”

Princeton team members (from left to right): Ilya Belopolski, Daniel Sanchez, Guang Bian, M. Zahid Hasan, and Hao Zheng. (Photo by Danielle Alio, Office of Communications.)