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Good Vibrations

UT's Steven Johnston and Colleagues Find that Phonons Boost Superconductivity in Iron Selenides

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Assistant Professor Steven Johnston and his colleagues have found that given the right environment, an underdog superconductor can set records. The results of those efforts were published November 13 in a *Nature* Letter entitled "Interfacial mode coupling as the origin of the enhancement of T_c in FeSe films on $SrTiO_3$."

A superconducting material exhibits no electrical resistance. The efficiency of uninterrupted current results in seemingly boundless applications: superconducting magnets for "floating" trains, compact power cables, and biomagnetic technologies are only a handful of examples. How superconductivity originates, however, isn't entirely simple, and it has to do with how electrons behave.

Typically, electrons repel one another. Yet there are circumstances that induce them to pair off, clearing all resistance and ushering along current unimpeded. This phenomenon comes in variations: there are low-energy (conventional) superconductors, where resistivity vanishes at transition temperatures around 39 Kelvin or lower. Here, electron pairing is caused by phonons: vibrations in a material's lattice-like structure (often described as a jungle gym). In the mid-1980s, high-temperature (or high-T_c) superconductors arrived, and they've shown an ever-increasing rise in transition temperatures. Yet how they become superconducting in the first place has been something of a mystery, as some schools of thought had ruled out phonons as candidates. That's part of what makes this *Nature* Letter all the more interesting.

Johnston and colleagues (including UT Physics alumnus Robert Moore, now with the Stanford Institute for Materials and Energy Sciences) investigated iron selenide (FeSe) films and found that phonons have a role to play in high-T_c superconductors after all. They grew the films (all of one unit cell thick) on a base layer, or substrate, of strontium titanate ($SrTiO_3$). Using photoemission spectroscopy, they found duplicate energy bands in the resulting spectra—called "shake-off" or "mirage" bands. These are the result of the iron selenide electrons' interaction with phonons in the $SrTiO_3$ substrate.

"The fact that they're there is important," Johnston explained of these duplicate bands, but "what's more important is that they're actually complete carbon copies of the bands above them," which explains how the lattice coupling occurs and that it's beneficial to pairing. He and colleagues at Stanford have long embraced the idea that high-temperature superconductors, like their low-energy cousins, could trace their superconducting origins to phonons. This research, he said, "is the most conclusive demonstration of that."

Interestingly, an iron selenide is actually a somewhat unlikely actor for such a starring role, but phonon interactions with strontium titanate elevate its status.

"Compared to other unconventional superconductors, it's pretty unimpressive on its own," Johnston said of the FeSe film, but "that layer seems to interact with its environment in a way that's very interesting."

In fact, "the interaction seems to prove an ideal way of boosting the superconductivity of the films," wrote Jan Zaanen of Leiden University in a News & Views article that appears in the same issue of *Nature*.

Yet another impressive result of the research is that the superconducting energy gaps appear at a temperature close to the boiling point of liquid nitrogen (77 Kelvin): a record for iron-based superconductors. Given the abundance of nitrogen in the air, finding materials that superconduct in liquid nitrogen could open the door to more applications.

For Johnston, however, the beauty of the work lies in finding out more about how strongly-correlated electron systems work. He performed theory calculations, building models to investigate how the electronic states in FeSe coupled to the substrate. The research also ties in with some of his earlier work on copper-based superconductors (cuprates). A condensed matter theorist, he joined the faculty on January 1, 2014, and works with other CMP theorists and experimentalists both on campus and abroad. The co-authors on the *Nature* Letter include Robert Moore (as mentioned earlier) and other colleagues representing the Stanford Institute for Materials and Energy Sciences, the Stanford Synchrotron Radiation Lightsource, the Departments of Physics and Applied Physics at Stanford University, the University of California at Berkeley, and Lawrence Berkeley National Laboratory.

More Information

- ***Nature* Letter: Interfacial mode coupling as the origin of the enhancement of T_c in FeSe films on $SrTiO_3$ (http://www.nature.com/nature/journal/v515/n7526/full/nature13894.html)**
- ***Nature* News & Views: High-Temperature Superconductivity: Electron Mirages in an Iron Salt (http://www.nature.com/nature/journal/v515/n7526/full/515205a.html)**