

Towards Superconductivity at Room Temperature: A Study of Delayed Electronic Attraction

The delayed attraction between electrons has been investigated in high-temperature superconductor LSCO[†] by simulating the process of electronic shielding.

Lossless power transmission and personal quantum computers may sound like two unreachable clichés of future technology. These are, however, feasible scientific goals to reach since the main key behind both are room-temperature superconductors. Superconductivity is an exotic property of some materials at low temperature where electrons move together in an ordered fashion through the crystal without encountering collisions. This frictionless electronic motion is caused by an effective attraction between electrons, resulting in what is called *pairing*. Energy dissipation of a single electron cannot occur since it requires breaking the pairing with another electron, which costs too much energy. Currents thus persist after removing an external voltage since the energy of the moving electrons is not converted to heat.

No material has yet been synthesized which keeps its superconductivity at room temperature. Doped *cuprates*, a class of materials containing two-dimensional crystal planes made up of copper and oxygen, are superconducting up to about halfway to room temperature. Understanding the pairing in the cuprates can thereby provide clues for pushing this higher, ultimately reaching room temperature. In the cuprates, the pairing is known to be confined to the copper-oxide planes. What is not known is the actual dominating mechanism behind the pairing, in other words, the main cause of attraction. Our investigation suggests that electronic shielding, more commonly called *screening*, could have a more important role in pairing than previously thought. This was seen by plotting the *screened interaction*, a measure of the effective forces between electrons, as a function of space and time.

Two single electrons repel each other, but in a system with a large number of electrons, two electron will not necessarily repel due to the presence of the surrounding interacting electrons. Just like throwing a rock into the sea, imagine throwing an electron into a material and studying the resulting waves in the screened interaction. These propagating waves correspond to attraction between electrons at the troughs and repulsion at the crests. In this work, by taking the time-average of these waves, large regions with an average attraction were found in the copper-oxygen planes of LSCO, a prototypical cuprate. On the contrary, such regions were not seen in the similar vanadium-oxygen planes of SVO^{††}, a non-superconducting metal.

While this significant difference between LSCO and SVO was for the time-average, studying these screened interaction waves not only as a function of space, but also of time, allowed for further insight. After introducing and removing an electron to the copper-oxygen planes of LSCO, other electrons got repelled, leading to a reduction of electrons in the surrounding region and thus to a delayed attraction. This attraction then reestablished a high density of electrons in the region which then caused similar, but more complex, cycles of repulsion and attraction. These oscillations turned out to decay very quickly. The first few cycles are thus likely to be particularly important for the pairing.

Comparing several different cuprates is a natural next step. The hope is to find a correlation between the extent of electronic attraction and the temperature at which superconductivity disappears. For this, the space-time approach developed in this work will be crucial.

About the author

This master thesis was performed at Lund University by Tor Sjöstrand with the supervision and support from Ferdi Aryasetiawan and Fredrik Nilsson.

[†]La_{2-x}Sr_xCuO₄ (*x*: doping concentration), ^{††}SrVO₃.