

Electron Phonon Interaction In Conventional And Unconventional Superconductors: Exploring the Fundamental Forces Behind Superconductivity

Superconductivity is a fascinating phenomenon that has intrigued scientists for decades. The ability of certain materials to conduct electricity with zero resistance at low temperatures has paved the way for revolutionary advancements in various fields. Understanding the mechanisms behind superconductivity is essential to harness its potential and utilize it in practical applications.

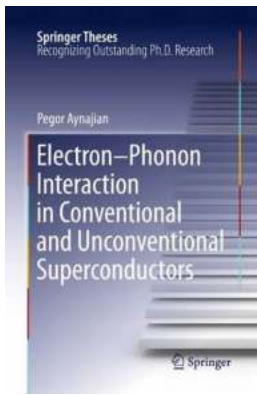
What is Superconductivity?

Superconductivity is a state where a material can conduct electric current without experiencing any resistance. This extraordinary property arises when the material's temperature is extremely low, often close to absolute zero.

Conventional superconductors, discovered in the early 20th century, derive their superconducting capabilities from the interaction between electrons and lattice vibrations known as phonons.

Electron-Phonon Interaction: The Key to Conventional Superconductivity

In conventional superconductors, the main driving force behind superconductivity is the interaction between electrons and phonons. Phonons are vibrational waves in the crystal lattice, and they result from the collective motion of atoms within the material. When an electron interacts with a phonon, it experiences a change in momentum, leading to a decrease in its kinetic energy.



Electron-Phonon Interaction in Conventional and Unconventional Superconductors (Springer Theses) by Pegor Aynajian (2011th Edition, Kindle Edition)

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This electron-phonon interaction plays a crucial role in the formation of Cooper pairs, which are fundamental in conventional superconductivity. Cooper pairs are composed of two electrons with opposite momenta and spins, held together by the exchange of phonons. The lattice vibrations create a favorable environment for the electrons to form these pairs, enabling them to move through the material without encountering any obstacles.

The BCS Theory: Explaining Conventional Superconductivity

In 1957, John Bardeen, Leon Cooper, and John Robert Schrieffer developed the Bardeen-Cooper-Schrieffer (BCS) theory, which provided a comprehensive explanation for superconductivity in conventional materials. The BCS theory describes the formation of Cooper pairs through the exchange of phonons, allowing for a macroscopic wave function that represents the collective behavior of the pairs.

According to the BCS theory, superconductivity occurs when the temperature is lower than a critical temperature called T_c . Below this critical temperature, the material undergoes a phase transition, and the electrons condense into a

coherent state. The BCS theory also predicts the existence of an energy gap in the electronic spectrum, which hinders the presence of any single-particle excitations.

Unconventional Superconductivity: Beyond the BCS Theory

While conventional superconductors exhibit superconductivity due to electron-phonon interaction, there are also unconventional superconductors that challenge the traditional BCS theory. Unconventional superconductors emerge in materials where electron-electron interactions play a significant role, outweighing the effect of electron-phonon interactions.

Unconventional superconductivity encompasses various types, such as high-temperature superconductors and heavy fermion superconductors. These materials often have complex crystal structures and exhibit unique properties that cannot be explained solely by the BCS theory.

Alternate Mechanisms for Unconventional Superconductivity

There are alternative mechanisms proposed to explain unconventional superconductivity. One such mechanism is the interaction between electrons through magnetic spin fluctuations. In some unconventional superconductors, the attractive interaction between electrons arises from their exchange of spin fluctuations, rather than phonons.

Another proposed mechanism involves the presence of a strongly correlated electron system, where electron-electron interactions dominate. In these systems, the interplay between electronic correlations and quantum fluctuations can lead to the formation of unconventional superconducting states.

Exploring Superconductivity's Potential

Understanding both conventional and unconventional superconductivity is crucial in unlocking their potential for technological advancements. The zero-resistance property of superconductors makes them highly efficient in energy transmission, leading to the development of more efficient power grids and electronic devices.

In addition to energy applications, superconductivity also holds promise in areas such as quantum computing and magnetic levitation. Quantum computers, which rely on the manipulation of quantum states, could benefit from superconducting qubits with their stable and coherent nature. Magnetic levitation based on superconductors allows for frictionless transportation and has already been utilized in magnetic levitation trains.

Electron-phonon interaction forms the foundation of conventional superconductors, enabling the formation of Cooper pairs and the emergence of superconductivity. However, unconventional superconductors challenge the traditional BCS theory by relying on alternative mechanisms and electron-electron interactions.

The study of superconductivity continues to captivate scientists as they seek to unravel the fascinating behavior of materials at ultra-low temperatures. Through further research, advancements, and a deeper understanding of electron-phonon and other interactions, we can harness the true potential of superconductivity for a wide range of applications and technological breakthroughs in the future.

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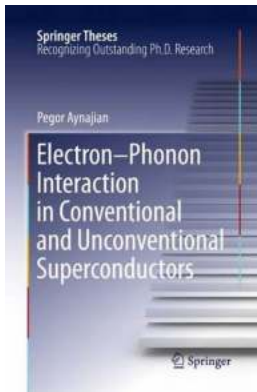
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The problem of conventional, low-temperature superconductivity has been regarded as solved since the seminal work of Bardeen, Cooper, and Schrieffer (BCS) more than 50 years ago. However, the theory does not allow accurate predictions of some of the most fundamental properties of a superconductor, including the superconducting energy gap on the Fermi surface. This thesis describes the development and scientific implementation of a new experimental method that puts this old problem into an entirely new light. The nominee has made major contributions to the development and implementation of a new experimental method that enhances the resolution of spectroscopic experiments on dispersive lattice-vibrational excitations (the "glue" responsible for Cooper pairing of electrons in conventional superconductors) by more than two orders of magnitude. Using this method, he has discovered an unexpected relationship between the superconducting energy gap and the geometry of the Fermi surface in the normal state, both of which leave subtle imprints in the lattice vibrations that could not be resolved by conventional spectroscopic methods. He has confirmed this relationship on two elemental superconductors and on a series of metallic alloys. This indicates that a mechanism qualitatively beyond the standard BCS theory determines the magnitude and anisotropy of the superconducting gap.



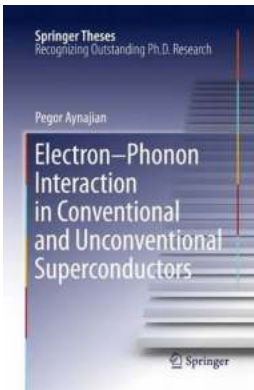
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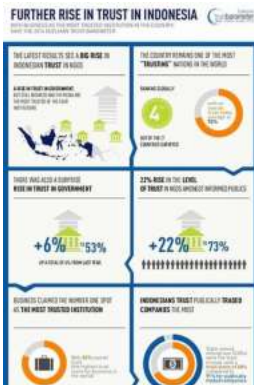
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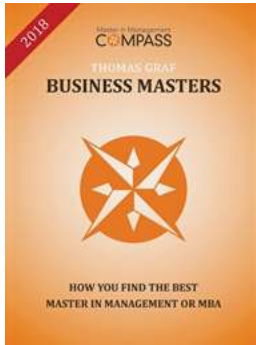
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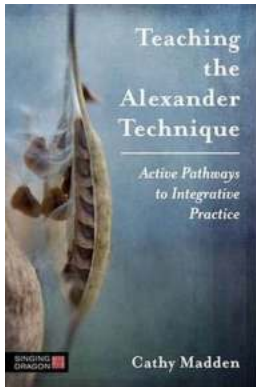
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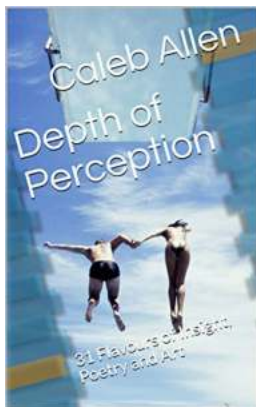
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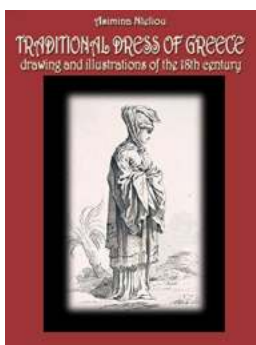
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