frontiers | Frontiers in Physics

TYPE Editorial
PUBLISHED 26 August 2024
DOI 10.3389/fphy.2024.1478445

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OPEN ACCESS

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RECEIVED 09 August 2024
ACCEPTED 19 August 2024
PUBLISHED 26 August 2024

CITATION
Prozorov R, Sauls JA, Hirschfeld P, Hussey NE and Iavarone M (2024) Editorial: Disorder and superconductivity: a 21st-century update. *Front. Phys.* 12:1478445.
doi: 10.3389/fphy.2024.1478445

Editorial: Disorder and superconductivity: a 21st-century update

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KEYWORDS

supeconductivity, supercondcutors, disorder, disorder-compounds, high-T_C

Editorial on the Research Topic
Disorder and superconductivity: a 21st-century update

Studying defects and imperfections in superconductors is paramount for fundamental and applied research. Defects play a multifaceted role, from decreasing quality and performance in some situations to enhancing desired properties in others. Disorder is also a unique probe to study the fundamental aspects of superconductivity. In classical s-wave isotropic superconductors, only pair-breaking (magnetic) scattering suppresses the order parameter, hence the transition temperature, T_c. In superconductors with an anisotropic gap, both potential and pair-breaking scattering suppress T_c, and in unconventional superconductors, the non-magnetic disorder can suppress superconductivity completely. Understanding the mechanisms through which defects influence the properties of superconductors is key to advancing the development and optimization of high-performance superconducting materials for modern technologies.

This Frontiers of Physics Research Topic–"*Disorder and superconductivity: a 21st-century update*"–contains an open-access Research Topic of three review articles and five original research articles highlighting several aspects of this broad area of modern research.

Alloul reviews the paramount role of disorder in determining some normal- and superconducting-state properties of high-T_c cuprate superconductors, in particular its effect on the T-doping phase diagram. Focusing on $YBa_2Cu_3O_{7-x}$ as the least disordered cuprate in the pristine state, controlled defects were introduced by spinless (Zn, Li) impurities substituted on the planar Cu sites. Another type of atomic disorder was introduced by electron irradiation. The review focuses on the Kondo-like physics emerging due to disorder and its connection to pseudogap and strange metal phases, and the use of isolated impurities to probe the correlations in the surrounding pure host.

Andersen et al. review spontaneous time-reversal symmetry breaking (TRSB) by disorder in superconductors. They discuss the possible nature of the superconducting ground state in materials where such TRSB was observed. While the most straightforward explanation comes from considering at least two different superconducting order parameters, it is shown that even in the case of a single order parameter TRSB may occur locally due to localized orbital current patterns or spin-polarization near atomic-scale impurities, twin boundaries and other defects.

Mishra et al. both present new data and review existing data on the thermal conductivity of nonunitary triplet superconductors with specific application to UTe_2. Thermal conductivity is a unique bulk probe of nodal quasiparticles and in this paper the authors derive a general expression for the thermal conductivity of a spin triplet superconductor. By varying the direction of the heat flow it is possible to map out the structure of the order parameter, and particularly distinguish between line and point nodes. Their analysis is assisted by comparing theory to samples with varying levels of disorder.

Juskus et al. highlight the apparent insensitivity of T_c to residual resistivity in various single-layered cuprates. By analyzing the results of T_c suppression in Bi2201, LSCO and Tl2201, the authors suggest that either we do not understand the origins of residual resistivity in cuprates or that the accepted paradigm of dirty d-wave theory may be invalid. The authors then present an alternative, non-BCS interpretation for the different extents of the superconducting dome in the three cuprate families.

Curro et al. study critical dynamics near the quantum phase transition in $TmVO_4$ where ferroquadrupolar order is suppressed by a magnetic field and identify a unique form of the hyperfine coupling that exclusively probes the transverse field susceptibility. The results show that this quantity diverges at the critical field, in contrast to the mean-field prediction. Further analysis suggests the presence of quantum Griffiths phases. This form of inhomogeneous and correlated disorder is largely absent from theories of disordered superconductivity, except for superfluidity of ^3He in dilute random solids like silica aerogels.

Ngampruetikorn and Sauls develop a theory of thermal transport and anomalous thermal Hall effect as well as electrical conductivity for chiral superconductors belonging to even or odd-parity E_1 and E_2 representations of the tetragonal and hexagonal point groups. Chiral superconductors exhibit novel properties that depend on the topology of the order parameter and Fermi surface, and, importantly for our Research Topic, the structure of the impurity potential. An anomalous thermal Hall effect is predicted and shown to be sensitive to the winding number, ν, of the chiral order parameter via Andreev scattering. For heat transport in a chiral superconductor with point-like impurities, a transverse heat current is obtained for $\nu = \pm 1$, but vanishes for $|\nu| > 1$. Their theory provides quantitative formulae for analyzing and interpreting thermal transport measurements for superconductors with broken time-reversal and mirror symmetries.

Wang et al. present their experimental results on zinc-doped $Bi_2Sr_2CaCu_2O_{8+x}$ high-T_c cuprate superconductor. Zinc exchanged for copper strongly suppresses superconductivity and acts as impurities with a strong quasiparticle scattering resonance. Using scanning tunneling microscopy, they investigate the electronic structure on the atomic scale around a Zn impurity. They conclude that the measured impurity-induced bound state pattern is strongly influenced by Bi atoms on the surface and therefore supports the “filter” theoretical model of the nonlocal interlayer tunneling effect from the CuO_2 layer to the BiO layer on the surface.

Finally, Torsello et al. report unusually weak proton irradiation effects in the anisotropic superconductor $RbCa_2Fe_4As_4F_2$ with unusual properties in between those of the iron-based pnictides and the high-T_c cuprates. Combining a coplanar waveguide resonator technique with electrical transport and point-contact Andreev reflection spectroscopy, they study the effect of structural disorder on the critical temperature, the superfluid density and the superconducting gap. They find an unusually weak dependence of the superconducting properties on the amount of disorder in this material when compared to other iron-based superconductors under comparable irradiation conditions. Surprisingly, the nodal order parameter of $RbCa_2Fe_4As_4F_2$ is also robust against proton irradiation, with a two-band d-d model being the one that best fits the experimental data.

Author contributions

RP: Writing–original draft, Writing–review and editing. JS: Writing–original draft, Writing–review and editing. PH: Writing–original draft, Writing–review and editing. NH: Writing–original draft, Writing–review and editing. MI: Writing–original draft, Writing–review and editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

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