EDITORIAL

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A new generation

The mechanism behind high-temperature superconductivity has been an arena of fierce debate in the condensed matter community for 35 years. As the discussion mellows, the time is ripe for new ideas.

The observation of high-temperature superconductivity in 1986 was unexpected and remains unexplained. Existing theories could not explain the phenomenon and suddenly the field was rife with new, often conflicting, theories. In 2006, *Nature Physics* published a Feature, in which a number of big names in the field shared their perspectives. The responses made it clear that, 20 years later, not only was there no agreement on a solution but also no consensus about the exact nature of the problem. This month, we revisit this topic in a Viewpoint and through a panel discussion with some of our authors. Despite recent progress, big questions remain.

The prevailing theory of superconductivity, developed in the 1960s, explains the superconducting state of metals by the formation of Cooper pairs caused by the electron–phonon interaction at low temperatures. Cooper pairs behave like bosons and condense into a phase-coherent ground state where they can carry current without any scattering. The foundation of this theory is the Fermi liquid model, which ignores electron–electron interactions. But the theory breaks down for copper oxides and other materials — often called strange metals — that exhibit high-temperature superconductivity.

For a new theory of superconductivity, all assumptions must be questioned. Rather than starting from the Fermi liquid model, our panellists advocate for starting with a Mott insulator — a state that should conduct according to band theory but is in fact insulating because of electron–electron interactions. Comprehending such correlated systems requires a shift in the theoretical mindset. "We don't even know if we can claim that the basic ingredients [for high-temperature superconductivity], in fact, are electrons," remarks Philip Phillips, a panellist.

Thinking beyond electrons also poses practical difficulties. Most experimental techniques, such as scanning tunnelling microscopy (STM) and angle-resolved photoemission spectroscopy (ARPES), use electrons to probe the system. It is possible to indirectly probe the strange metal phase with STM, but the challenge is to know what to look for. Panellist Vidya Madhavan says "We need a better understanding of the consequences of the strange metal phase. It might require us to probe the same system but with many different techniques."

The early days of the field were full of heated debate over the mechanism of superconductivity in the cuprates. "The field used to be very contentious," reflects Phillips. Now, the general feeling is that the community is starting to get friendlier and more welcoming to young people. As the community has evolved, so has the science, and, over time, the discussion has moved beyond cuprates. Current research on high-temperature superconductivity draws on the work of a broader community, spanning many fields of physics[1].

Two recent discoveries could provide new insight. Nickel-based compounds had long been predicted to exhibit a superconducting phase due to electronic similarities with copper-based compounds. The superconducting phase was finally experimentally realized in 2019, although it is unclear whether there is a universal mechanism that explains both cuprates and nickelates[2]. Perhaps more unexpectedly, superconductivity has now also been observed in 2D twisted bilayer, or moiré, systems. Studying emergent superconductivity in a range of platforms may lead to new insights, as discussed in a *Nature Physics* focus issue last year.

As a Reviews journal, it is our job to keep on top of trends and publish timely reviews and analyses on the latest discoveries in a field. However, it is also worth reflecting on the older questions that remain unsolved. We hope that by regularly covering these topics in our pages, we can keep the discussion open and encourage new voices to join the conversation.

1. Hartnoll, S. et al. Quantum connections. *Nat. Rev. Phys.* **3**, 391–393 (2021).
2. Pickett, W. E. The dawn of the nickel age of superconductivity. *Nat. Rev. Phys.* **3**, 7–8 (2021).