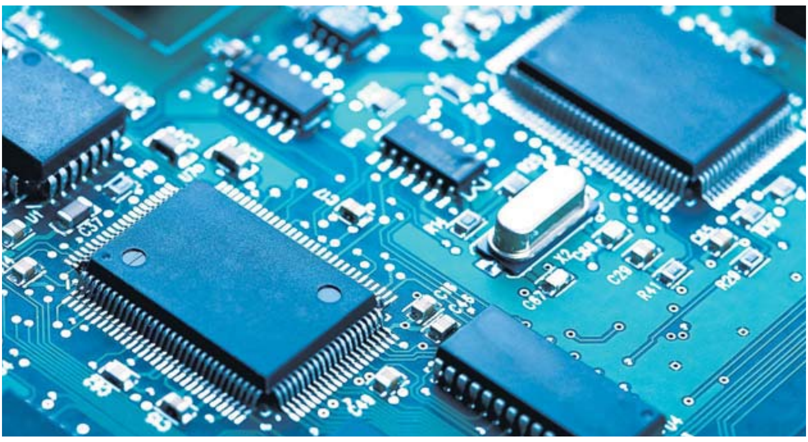

Theoretical truth

PHYSICS The first notes and observations on superconductivity marked the beginning of a race between scientists Heike Kamerlingh Onnes and James Dewar, to liquify helium. **C Sivaram** documents the series of discoveries that followed

The phrase "Kwik nagenoeg nul," meaning "quicksilver near enough null," scrawled in a lab notebook, some time in April 1911, signalled the discovery of superconductivity. The scrawl was made by Heike Kamerlingh Onnes, who with his colleagues Holst and Flim, discovered that resistance of liquid mercury when cooled to 4.2 degrees Kelvin reached a value so low that it was impossible to measure. This complete absence of electrical resistance characterises superconductivity.

This discovery marked the beginning of a race between Onnes and James Dewar to liquefy helium, in 1908. If the Leiden team had simply wired a piece of lead (or solder) lying around their lab their work would have been easier, for lead has a high superconductivity power, at an ever higher temperature of 7.2 degrees.

Following a suggestion by Paul Ehrenfest, three years later, they produced and measured "persistent currents" (which in theory could last a billion years) in a lead-ring sample. Onnes won the Nobel Prize in 1913 for successfully liquefying helium. The discovery, first published in English in the Dutch Journal Communications from the Physical Laboratory at the University of Leiden (120b, 1911), shocked the scientific community.

After the seminal 1911 discoveries, further research received setbacks for nearly two decades for two reasons. The first was building similar facilities to that of Leiden was expensive and difficult and the secondly, the state of zero-resistance vanished when the superconducting sample was exposed to even modest magnetic fields!

Meanwhile, other labs in Europe and North America began developing liquid helium cryogenic facilities. In 1933, Meissner and Ochsenfeld observed that any magnetic field near a superconducting sample was expelled once it had been cooled below the temperature at which it loses all resistance.

Later, Keesom and Kok observed that the derivative of the specific heat of a superconductor could suddenly jump when the material is cooled below transition temperature. These twin effects helped formulate the term 'flux expulsion'.

In the mid-1930s, Shubnikov discovered superconductivity in metallic alloys. These alloys were dubbed 'Type II superconductors'. They quickly dominated research, especially in Russia, under the leadership of Kapitsa, Landau and Shubnikov. Stalwarts like Ginzburg, Abrikosov and Gorkov also began working in experimental and theoretical research in superconductivity. Much of this work was unknown to the West at that time. The Ginzburg-Landau–Abrikosov-Gorkov or "GLAG" model, even today, underlies all practical applications of superconductivity and related phenomena!

After the discovery of Type II superconductors, (where the field penetrates the sample to finite depth), the London brothers—Fritz and Heinz London—made the first theoretical breakthrough in 1935. They proposed a phenomenological adjustment to Maxwell's constituent equations to accommodate the notion of 'penetration depth' of an applied magnetic field. They formulated two equations for this.

However, progress in understanding the microscopic basis of the phenomena took two more decades, finally leading to what is now called the 'BCS theory' (after Bardeen, Cooper and Schrieffer) in 1957 and for which they shared a Nobel Prize in 1972.

The key developments leading to the theory included the work by Cooper that an electron gas is unstable in the presence of weak attractive interactions, leading to electron pairs binding together and an experimental observation by Emanuel Maxwell in 1950. This suggested the involvement of lattice vibrations or 'phonons'. The BCS theory showed that, given the right conditions, these vibrations could yield the required attractive interactions that allow electrons to pair up, enabling the material to conduct without resistance.

Most superconductors follow the general prescription formulated by BCS, but quite unlike in the framework for example of semiconductor band theory that facilitates the design of bridges, circuits or chips, BCS is poor at pointing out what materials to use or develop to create new superconductors. Which is why the discovery of the so-called high temperature superconductors (above 30 deg.) in layered copper oxide perovskites by Bednorz and Muller in IBM in 1986, triggered a boom in experiments.

Within a year, the compound YBCO, was found to super conduct at an astounding 93 degrees, well above the boiling point of liquid Nitrogen. The record substantiated transition temperature is 138 degrees for fluorinated compound of mercury, barium, calcium and copper oxide (under pressure this can go up to 166 K).

In 2001, Japanese scientist Jun Akimitsu observed that cheap and simple chemical magnesium diboride (MgB2) could superconducts at 39K.

In 2006, another breakthrough by Hideo Hosono and colleagues, who discovered superconductivity in an iron compound, the highest in these materials is now around 55 K. (The highest in an organic superconductor involving bucky balls is at 38K).

Ass far as practical applications are concerned, with a few exceptions like superconducting magnets, there have been far fewer applications than lasers. There have been limitations in applying superconductivity to magnetically-levitated (maglev) trains. Every maglev system apart from the Yamanishi test line in Japan has used conventional technology. The top speed of the Yamanishi superconducting prototype is only six kilometers per hour faster than the ordinary wheel-on-rail French TGV trains!

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