University of Zurich[UZH]

K. Alex Müller
Nobel Prize in Physics 1987

Nobel Prize in Physics 1987 "for the pioneering discovery of superconductivity in ceramic materials"

* 20 April 1927 in Basel

1962–1970 Privatdozent
1970–1987 Adjunct Professor
1987–1994 Professor of Solid-State Physics at the University of Zurich

Müller's Submarine

Zollikon, December 2014: K. Alex Müller is a happy man. The 87-year-old physicist sits in front of his laptop and says: "I believe we've understood it." Understanding something is already special for a physicist. In this case, however, the thing understood concerns high-temperature superconductivity, Müller's magnum opus. Müller is convinced that he at last has a watertight explanation for the phenomenon that he and J. Georg Bednorz discovered 28 years ago: High-temperature superconductivity in copper oxides. This should bring a decades-long dispute to a happy end, at least from Müller's perspective. With his explanation, however, Müller has launched a new debate on the distribution of matter in the universe. But more of that later.

Erice, Sicily, summer 1983: K. Alex Müller is sitting on a bench in the castle grounds and enjoying the view. As he gazes into the distance, his mind buzzes with ideas. He had just listened to a lecture by Harry Thomas which dealt with the possible existence of Jahn-Teller polarons – "quasi-particles" that occur when electrons move through a crystal lattice. Thomas suspected that these polarons could result in superconductivity.

"As I sat there, gazing at the sea, the idea came to me that such polarons might occur in oxides," K. Alex Müller recalls. It seemed far-fetched, as oxides are ceramic materials with only very poor conductivity at normal temperatures. But they were also very familiar to Müller; he had worked on them all his life as a researcher, and had published foundational articles on them. Although he had never worked in the field of superconductivity, Müller, at the time 56 years old, decided to take on an entirely new challenge.

Müller had already voiced the idea that, under certain conditions, oxides might become superconductive. But no one took him seriously. "Exactly that motivated me. I wanted to swim against the current."

He says that he owes his persistence and his desire to think outside the box to his childhood, which was not easy, as Müller explains. The son of a salesman and grandson of a chocolate manufacturer, Karl Alex spent part of his childhood in Lugano. After the early death of his mother, when he was just eleven, he went to boarding school in Schiers. Holidays were spent with his

K. Alex Müller was 56 when he decided to take on a new challenge – researching superconductors.

grandmother at the Villa Sumatra in Chur, where he could forget the austerity of boarding-school life, again eat his fill, enjoy the bourgeois atmosphere, and sleep on mattresses of the finest horsehair, as he writes in his memoirs.

From 1946 to 1952, K. Alex Müller studied physics at ETH Zurich, where he attended courses taught by Wolfgang Pauli and Paul Scherrer. Pauli, for all his methodological precision, never lost a feeling for the unpredictability of nature and scientific processes – an attitude that Müller internalized: "Decisive events in science often occur entirely unexpectedly." Like Pauli, Müller showed an early interest in psychoanalysis, particularly in the interpretation of dreams. "It was always dreams that gave me confidence in myself and in the path I had taken," he says, looking back. In 1958, Müller earned his doctorate at ETH Zurich and began work as a research associate at the Battelle Memorial Institute in Geneva. Müller has fond memories of his time in Geneva – due to the charm of the city as well as to the birth of his daughter, Silvia. His son, Eric had already been born in Zurich. Family was, and remains, enormously important to K. Alex Müller. He met his wife, Ingeborg Marie Louise Winkler – his mentor, companion, and a substantial influence on his work – through her brother and Müller's fellow student, Ulrich Winkler. Ingeborg trained as a singer and performed as a soprano soloist in church concerts. The Müllers were regular visitors to the Zurich Opera.

In 1963 Müller and his family returned to German-speaking Switzerland after receiving a very attractive offer: A position at IBM's new research laboratory in Rüschlikon, with the possibility of teaching at the University of Zurich. While still in Geneva, Müller had lectured at the University of Zurich; in 1970 he became an adjunct professor and in 1987, just before receiving the Nobel Prize, he was appointed full professor. After his return from Geneva, he lived first in Affoltern am Albis; later, the family moved to a house of their own in Hedingen, where Müller lived until he moved to the Tertianum in Zollikon; he was declared an honorary citizen of Hedingen in 1988.

His double mandate at the University of Zurich and with IBM gave K. Alex Müller welcome room to maneuver: "When things were not going so well at IBM, I spent more time at the University, and vice versa." It was indeed his dissatisfaction with developments at IBM that caused Müller to devote more time to research. This came about as follows: In the 1970s, Müller was the head of the Physics Department in Rüschlikon. At that time, Heinrich Rohrer and Gerd Binnig were developing the scanning tunneling microscope that would earn them the Nobel Prize in 1986. The head of research at IBM was so impressed by this invention that he decided to focus all physics research in Rüschlikon on the further development of this process. K. Alex Müller opposed this decision, as he considered other projects to be equally important, and consequently resigned his position as head of department. This freed up time for his own research: "It was just as well; to me, research was always the most important thing." Looking back, it was undoubtedly the right decision, as it gave K. Alex Müller the time and the leisure to write physics history.

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>
> **K. Alex Müller**

He didn't, however, make his groundbreaking discovery alone but in collaboration with J. Georg Bednorz. At that time, Bednorz, previously Müller's doctoral student, was also working at the IBM laboratory in Rüschlikon. After returning from Erice, Müller took Bednorz into his confidence and suggested that they tackle the superconductor project together. Bednorz, then 33, agreed. They began their work confidentially, as a so-called "submarine project." Müller was able to research independently; as an IBM Fellow, he enjoyed the privilege of choosing his work as he deemed appropriate.

Rüschlikon, 27 January 1986: Georg Bednorz has just "brewed" lanthanum-barium-copper oxide. This, after three years of hard work in the laboratory, 80 synthesized compounds, and many set-backs, is the big breakthrough: A compound that will take superconductor research in entirely new directions. The critical temperature at which this copper oxide becomes superconductive is an astonishingly high minus 238 degrees. The findings are nothing short of a sensation, and the publication of the discovery unleashes a wave of enthusiasm. Soon laboratories around the world begin to apply this new knowledge, with copper oxides at even higher critical temperatures soon being found.

Just a year later, Müller and Bednorz were awarded the Nobel Prize in Physics. However, a veritable "religious war" still rages in physics over the theoretical explanation behind their discovery. Many physicists, particularly scientists in the USA, take the view that the difference to conventional superconductors is so great that an entirely new electronic theory is required. In contrast, K. Alex Müller and his successor in superconductor research at the University of Zurich, Hugo Keller, have demonstrated that, as with conventional superconductors, the interaction of the electrons with the oscillations of the crystal lattice is responsible for high-temperature superconductivity. Today, K. Alex Müller is convinced that he has supplied definitive proof – albeit proof with a surprising consequence. As is the case with metallic superconductors, the so-called Cooper pairs – in this case bipolarons – enable the current to flow without resistance. In oxides, however, the bipolorans are not distributed evenly. "The areas that are superconductive change dynamically," says Müller. "There are some with a big charge, and some with no charge."

On the back of this discovery, Müller has taken a bold step from copper oxides to the cosmos: "When you look into the night sky, you see clusters of stars, areas that are light, and areas that are dark. The universe is not homogeneous." In his General Theory of Relativity, however, Einstein postulated that matter in the cosmos is indeed homogeneous. "If he were right" maintains Müller, "the universe should be evenly illuminated. This is not the case." For, like the charge in the superconductive cuprates, matter in the universe is not evenly distributed. "Accordingly, we must rethink the Theory of Relativity," Müller concludes, throwing down the gauntlet to the scholars of the future. *Thomas Gull*

Contention still rages in physics today over the theoretical explanation behind Müller's discovery.

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Superconductors – Oxides Beat Metals

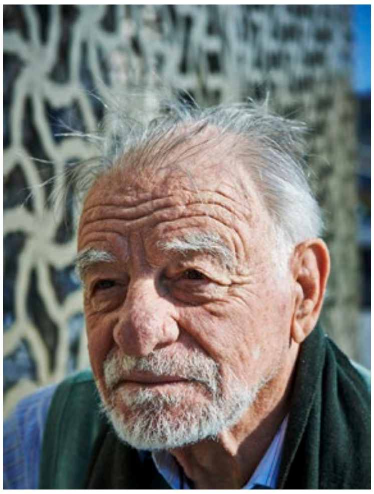
When, in 1983, K. Alex Müller and J. Georg Bednorz began their search for a high-temperature superconductor in ceramic compounds, superconductor research had arrived at a dead end. In metallic compounds, which had traditionally been investigated for superconductivity, scientists were unable to significantly increase what is known as the critical temperature at which a material becomes superconductive. At the time, the highest critical temperature of a metallic compound was minus 255 degrees Celsius.

That metals could be superconductive had already been discovered by the Dutch physicist Heike Kammerlingh Onnes in 1911, when he cooled mercury to minus 268.5 degrees Celsius and observed that electric resistance disappeared. Further metallic superconductors were subsequently found, and in 1933, German physicists Walther Meissner and Robert Ochsenfeld discovered the eponymous Meissner-Ochsenfeld effect, which demonstrates how a superconductor entirely "expels" an external magnetic field from its bulk. This makes a superconductor not only an ideal conduit for electricity, but at the same time a strong diamagnet. Since Meissner-Ochsenfeld's discovery, a superconductor must meet two criteria: It must conduct electricity without resistance, and it must expel the magnetic field from its bulk.

After initial successes, superconductor research with metals stagnated. The problem was that metallic compounds become superconductive only at temperatures a little above absolute zero, minus 273 degrees Celsius. They must therefore be cooled with liquid helium, a difficult and expensive procedure.

The first superconductive compound produced by Bednorz and Müller, lanthanum-barium-copper oxide, becomes superconductive at minus 243 degrees. While no great difference in temperature, this represented a huge scientific advance because the new material immediately opened up new possibilities. As became quickly clear, the critical temperature of oxide compounds is significantly higher than in metals. Today, the highest critical temperature for copper oxides is minus 110 degrees.

A high critical temperature has the great advantage that superconductivity is achieved by cooling with liquid nitrogen, making technical applications much simpler and cheaper. It is used today in power stations, transformers, medical technology, power transmission, and microelectronics. *(TG)*



K. Alex Müller, 2014. Photo: René Ruis

Discovered high temperature superconductivity: K. Alex Müller and J. Georg Bednorz in their lab at IBM in Rüschlikon. Photo: IBM Research - Zurich

In tandem to the Nobel Prize: Physicists K. Alex Müller and J. Georg Bednorz