Michael Tinkham

1928–2010

BIOGRAPHICAL *Memoirs*

A Biographical Memoir by
John Clarke, Isaac F. Silvera,
and Malcolm R. Beasley

NATIONAL ACADEMY OF SCIENCES

MICHAEL **TINKHAM**

February 23, 1928–November 4, 2010

Elected to the NAS, 1970

Michael ("Mike") Tinkham was a towering figure in both experimental and theoretical aspects of magnetism and superconductivity. His research in superconductivity—the phenomenon by which some materials lose their electrical resistance when cooled below their transition temperature—continued throughout his career. Mike's first major achievement was to demonstrate the existence of a superconducting "energy gap" by showing that light below a certain frequency was transmitted much more readily through a superconducting film than through a normal metal film. This counter-intuitive result was a landmark confirmation of the famous Bardeen-Cooper-Schrieffer theory of superconductivity. Subsequently, he showed that thermal fluctuations of the macroscopic quantum wave function in superconductors were important by demonstrating fluctuation-enhanced diamagnetism in bulk superconductors above the transition temperature and resistance in superconducting filaments below the transition temperature.

M. Tinkham

By John Clarke,
Isaac F. Silvera,
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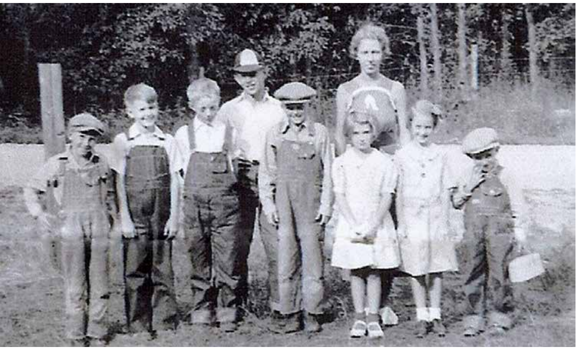
Mike later elucidated the theory of so-called "charge imbalance," which explains how disequilibrium between electron-like and hole-like quasiparticles leads to a static voltage in superconductors in regions where normal currents convert to supercurrents or supercurrents to normal currents. Specifically, the theory describes the properties of electrical transport across a normal-superconducting interface, and accounts for the behavior of "phase-slip centers"—the flow of flux quanta across superconducting filaments. He also studied arrays of Josephson junctions as a model for two-dimensional phase transitions.

Mike was a member of the U.S. National Academy of Sciences and a Fellow of the American Academy of Arts and Sciences, the American Physical Society (APS), and the American Association for the Advancement of Science. He received the Oliver E. Buckley Prize of the APS in 1974 "for his experimental investigations of the electromagnetic properties of superconductors" and the Fred E. Saalfeld Award for Outstanding Lifetime



Mike with fellow students and teacher from the one-room school house. Mike is second from the left, already displaying his trademark grin. (Photo courtesy Mary Tinkham.)

Achievement in Science from the Naval Research Laboratory in Washington, DC, in 2005. He held honorary degrees from Ripon College (his undergraduate alma mater) and the Eidgenössische Technische Hochschule, Zürich.

Early years

Mike was born in a farmhouse in Brooklyn Township, Wisconsin (in Green Lake County), on February 23, 1928, the middle child of Clayton and Laverna Tinkham; Mike had an older brother Clayton and younger sister Natalie. Both parents had received degrees from Ripon College (Ripon, WI), his father in chemistry and physics and Mike's mother in chemistry. His father was a farmer who also taught vocational agriculture and supervised veterans in a program for on-the-job training; when that program ended, he became a life insurance salesman. Mike spent his early childhood on the farm, and attended the one-room Forest Ridge School in Brooklyn before the family moved to Ripon. After experiencing that rural school, where students learned as much if not more from each other than from the one teacher, Mike always said that where you went to school didn't matter so much; what mattered was how you used that experience.

When Mike was 10, the family moved to Ripon to take care of his maternal grandmother, Grandma Krause, who insisted that he converse with her in her native German. Thus he grew up fluent in that language. Mike was fortunate in having an extremely good piano teacher, Lillian Zobel, and he became a highly accomplished pianist. In fact, he seriously considered becoming a musician, but, fortunately for physics, he decided against it, deeming physics to be a more financially reliable field than music. Mike never returned to playing the classical repertoire; he had worked so hard and drilled so much for the competitions he had entered, it was no longer a pleasure for him. But he could always be relied upon to entertain his family and friends, mostly with popular music played by ear, throughout his adult life.

Mike attended Ripon High School, where he distinguished himself by becoming a finalist in the Westinghouse talent search, which included an all-expenses-paid trip to Washington, DC. After completing Ripon, at the age of 18, Mike joined the Navy, spending much of his time at the Naval Station Great Lakes in northern Illinois. There he received training in electronics, which proved invaluable in his subsequent career. He also became an avid ham radio operator. To Mike's great regret, the entire class was thrown out of electronics school because a few of its members broke into an officer's mess and stole some liquor!

Following his sojourn in the Navy, Mike attended Ripon College, which at that time had a program whereby a student could attend Ripon for three years and then transfer to MIT to obtain both a bachelors' and masters' degree from that institution. Mike completed this process in 1951. He received his Ph.D. from MIT in 1954; his thesis, based on research supervised by Malcom Strandberg, was titled "Theory of the Fine Structure of the Molecular Oxygen Ground State with an Experimental Study of its Microwave Paramagnetic Spectrum."

Tinkham (Navy) with older brother Clayton (Army). (Photo courtesy Mary Tinkham.)

Mike then spent a postdoctoral year, 1954–55, at the Clarendon Laboratory of Oxford University, England, where he worked with Brebis Bleaney to explore the magnetic properties of transition-metal ions in a diamagnetic lattice. Mike thereafter became a postdoctoral scholar in the physics department at the University of California, Berkeley, beginning in 1955, and he joined the faculty there in 1957. In 1966, Mike moved to the physics department at Harvard University, where he was based for the remainder of his career.

Michael and Mary on the eve of their wedding.
(Photo courtesy Mary Tinkham.)

In 1960 Mike attended the wedding of a good friend whose bride invited a good friend of her own, Mary Merin. Because this was a very small wedding, Mike and Mary had a chance to become acquainted. It is apparent that he was a very persuasive guy because Mary was about to attend graduate school at Yale University and he convinced her that she should instead apply to Berkeley, as graduate admissions there did not close for another two weeks! She did, and in due course they married in New York City on June 24, 1961. They produced two sons, Jeffery Michael, born in 1966, and Christopher Gillespie, born in 1968.

Superconductivity and magnetism: Berkeley years

When he first arrived at Berkeley, as a postdoc in the solid state physics group established by Charles Kittel, Mike had already performed two very successful experiments using microwave-resonance techniques. For his doctoral thesis at MIT he had explored the fine structure of gaseous molecular oxygen; and with Bleaney at Oxford, in the then-flourishing field of magnetism, he studied transition-metal paramagnetic impurities in a diamagnetic crystal of zinc fluoride. But instead of continuing with microwave resonance Mike made a remarkable change, together with his postdoc colleague Rolf Glover III, to studying superconductivity—a phenomenon that had defied any fundamental theoretical understanding for almost half a century. Their technique involved transmission through thin superconducting films in search of a possible energy gap, estimated to be at terahertz frequencies. The challenge was to do broadband measurements in a spectral range, corresponding to millimeter and sub-millimeter wave radiation, known as the far infrared.

It is pertinent to reflect on the experimental techniques developed in the 1950s. Powerful sources such as klystrons had not yet been developed—the only available options were weak low-intensity sources and insensitive detectors. Mike and Rolf used a mercury discharge lamp, working in the tail of the black-body radiation curve with an effective temperature of about 10^4 K. The spectrum was dispersed with grating spectrometers, gratings being fabricated in the machine shop (as the grating constant for these wavelengths is relatively large). Sub-microwatt power radiation was funneled through light-pipe optics, through the samples, and onto a Golay cell detector with a sensitivity of 10^{-8} W/Hz1/2 at best, and read out with a homemade lock-in amplifier. With this setup in 1956, before the appearance of the theory of superconductivity developed by John Bardeen, Leon Cooper, and Robert Schrieffer (the BCS theory), Mike and Rolfe measured the absorption of far-infrared light passing through thin films of superconductors. And they found that the light was transmitted much more readily than in a normal metal film.

Given the state of knowledge at the time, this finding was at first glance a contradiction: because superconductors conduct infinitely better than normal conductors, one might naively expect them to reflect light much more strongly. But when Mike and Rolfe contacted Bardeen, he said that the results were “not entirely unexpected.” Mike and Rolf performed a pioneering Kramers-Kronig analysis of their data, which was uncommon in those days, obtained the frequency dependence of the real and imaginary parts of the conductivity, and extracted the gap energy. The experimental results, in particular the Tinkham-Glover measurements of the temperature dependence of the energy gap, were a key confirmation of the BCS theory.

When Mike joined the faculty of Berkeley’s physics department in 1957, he quickly attracted a group of students, with Don Ginsburg, Bob Ohlmann, and Paul Richards being the first. Ginsburg and Richards studied superconductivity, while Ohlmann pursued magnetism. Using far infrared (IR) apparatus, Ohlmann found the antiferromagnetic resonance in single crystals of iron fluoride at ~52 cm-1 (~520 microns) at low temperature; and he studied the temperature dependence of the sublattice magnetization, confirming recently developed theory. Ginsburg continued to study several superconducting elements by transmission. Richards improved the far IR apparatus; by replacing the Golay cell with bolometers cut from carbon resistors and cooled to helium temperatures, he obtained an increase of 20 in the signal-to-noise ratio. This enabled the study of reflectivity from bulk superconducting metals and the determination of the energy gaps.

In the early 1960s, Mike's students continued to innovate. Stan Barker studied ferroelectrics in the far IR and Al Sievers the infrared properties of rare earth iron garnets; Ray White and Don Morris continued with superconductors and, before Mike's departure to Harvard, Leigh Palmer carried out a tour-de-force experiment with simultaneous transmission and reflection measurements on superconductors. Early on, Mike had been hands-on in the lab, guiding the students. But by the 1960s, while he still visited the labs and students daily, he spent most of his time working on theory and analysis in his office. Either way, Mike inspired his students; he sparked their scientific curiosity and gave them plenty of room to explore new ideas.

One of us (IFS) was given a project, following that of Sievers, to study rare earth orthoferrites, but I found them to be too complicated and proceeded to study multi-sublattice canted antiferromagnets. While Mike was away on sabbatical leave and I was writing my thesis, I found that a sum rule derived from Kramers-Kronig relations was not saturated. Mike always gave his students plenty of space to explore new ideas in any stage of their Ph.D. program, and always with his guidance. He put me in contact with Charles Kittel for theoretical supervision. I retreated from writing, and discovered two-magnon absorption in antiferromagnets.

During his time as a member of the Berkeley physics faculty, Mike developed his legendary teaching skills. A byproduct of his classroom teaching was his first book, Group Theory and Quantum Mechanics. But when Mike became a bit restless at Berkeley, which was in the midst of the student Free Speech Movement, he was successfully recruited by Nicolaas Bloembergen and departed for Harvard in 1966.

At that time, the field of superconductivity was itself undergoing a major transition, following the remarkable period of discovery from 1957 to 1962. The BCS theory had been introduced and experimentally confirmed. Type-II (i.e., very high-magnetic field) superconductivity was discovered, and the phenomenological Ginzburg-Landau theory was shown to follow from BCS theory. This work also established the physical meaning of the Ginzburg-Landau order parameter as the macroscopic quantum wave function of the Cooper pairs. Last but not least, the Josephson effect was predicted and confirmed. These remarkable advances led to a new, dynamic, and productive era of superconductivity that allowed entirely new questions to take center stage.

Early Harvard years

After Mike moved to Harvard, I (MRB) joined his group, first as a postdoc and then as an assistant professor. Together we began to address some of these new questions. One was whether or not thermal fluctuations of the pair-wave function were important in superconductivity. The prevailing view, based on the ideas of critical phenomena, was that they were not, due to the very large coherence lengths typical of superconductors. In a Tinkham group meeting, I hypothesized that if fluctuations were important, there should be a fluctuation-enhanced diamagnetism (i.e., a precursor to the Meissner effect) as the transition temperature was approached from above. Mike, with his sensitive nose for new physics, became very animated, and we were off and running.

Upon hearing this idea, Albert Schmid confirmed our intuition theoretically. Then, using a very sensitive SQUID (Superconducting QUantum Interference Device) magnetometer of the sort that I had developed as part of my Ph.D. thesis research, Mike, graduate student Jerry Gollub, and I demonstrated that such fluctuation diamagnetism could be observed—indeed, observed at up to twice the transition temperature. This result, and the prior observation of fluctuation-enhanced conductivity above the transition temperature by Rolf Glover (who had moved to the University of Maryland, College Park, after leaving Berkeley) put to rest the prevailing view that fluctuation effects were negligible. The theorists had focused on critical fluctuations, whereas the fluctuations we observed were classical (Gaussian) fluctuations within mean-field theory.

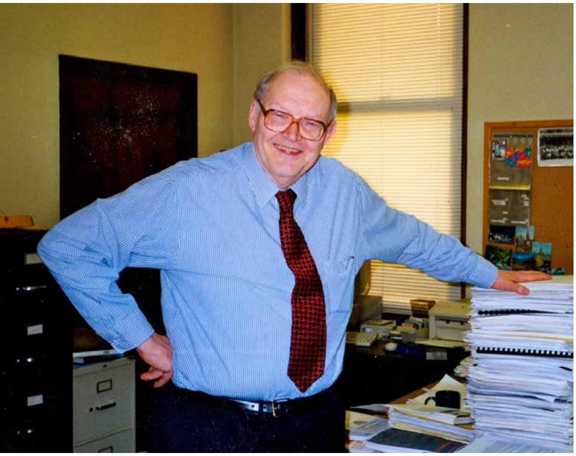
Perhaps an even more important question was whether thermal fluctuations below the transition temperature could lead to resistance in superconducting filaments (i.e., homogeneous one-dimensional superconducting wires), as predicted by D. E. McCumber and B. I. Halperin based on the earlier work by J. S. Langer and M. E. Fisher for the analogous situation in superfluid helium. The key idea here was that thermal fluctuations could cause the superconducting pair-wave function to undergo a thermally activated instability that would cause the wave function to locally lose a 2π twist in its phase. This outcome, as first emphasized by B. D. Josephson, would necessarily produce a voltage pulse V(t) with a quantized time-integrated weight equal to the flux quantum Φ_0 of superconductivity [that is, $\int V(t)dt = \Phi_0$].

This is the famous phase-slip process, in the modern parlance of superconductivity. It means that in the presence of an applied current, superconductors can generate a static voltage (and hence resistance) from a steady rate of phase slips. Such a fundamental and elegant idea clearly demanded experimental confirmation. Two teams were involved in the chase—the Harvard group (Mike, graduate student Ron Newbower, and I) and the Cornell group (Watt Webb, James Lukens, and Richard Warburton). As it happened, the Cornell researchers were the first to report convincing confirmation of the McCumber-Halperin theory. Shortly thereafter, our group also confirmed the predictions, and we provided a more quantitative test of the theory.

The next natural question about phase slips in filamentary superconductors was how they generated the current-voltage (I-V) characteristics of these one-dimensional superconductors. To our initial surprise, the voltage did not develop continuously but rather through a series of essentially identical discrete steps followed by a linear differential resistance that increased by the same amount with each voltage step. After a bit of reflection, we realized that this behavior was the result of a series of spatially separated localized phase-slip centers of identical character forming along the filament as the current increased. While these ideas provided a good qualitative explanation of the I-V characteristics, a quantitative understanding required a theory that could calculate the magnitude of the differential resistance. Only later, when Mike returned from his sabbatical at Cambridge University, fresh with the ideas that he and John Clarke (who was also at Cambridge on sabbatical) had developed regarding the microscopic phenomenon of charge imbalance in superconductors, could we tackle the issue of the magnitude of the differential resistance of a phase-slip center. From this effort came the Skocpol-Beasley-Tinkham theory of phase-slip centers, which showed that the differential resistance was governed by the decay length of charge imbalance studied by Mike and John.

While this work on phase-slip centers was being completed, I (MRB) left Harvard to take up a position at Stanford, but Mike continued to probe ever deeper into the nature of resistance in filamentary superconductors. As time went on, the main question became: do quantum fluctuations of the pair-wave function lead to phase slips as the temperature of the filament approaches absolute zero? In his last published paper on the subject, Mike and his coauthors concluded that quantum fluctuations do indeed produce such resistance. Time will tell whether they were correct.

Mike also worked on other important problems in superconductivity. Notable among them was the behavior of Josephson-junction arrays, both for their own sake and as a model system for the famous Kosterlitz-Thouless-Berezhinskii theory of two-dimensional phase transitions. The team of Mike, Chris Lobb (then an assistant professor at Harvard), and graduate student David Abraham studied the resistive transition of such arrays from the perspective of that theory. Later, again with Lobb and Abraham, Mike studied the response of these arrays to an applied field in which the interplay between the vortex lattice and the periodicity of the array animated the physics. Given his powerful mastery of the phenomenology of superconductors, Mike made two insightful contributions to high-temperature superconductivity. With Lobb and two graduate students, Lydia Sohn and Gabriel Spalding, he showed that the simple critical-state model of classical superconductors could account for the harmonic generation observed in oscillating magnetic fields in the cuprate superconductors. And Mike became the first to point out that thermal fluctuations would substantially broaden the resistive transitions of the high-temperature superconductors and might thereby limit their utility.



"That shows the job of the advisor—turning the graduate student into papers.".
(Photo courtesy Daniel Prober.)

A final important contribution was Mike's analysis of current flow across a superconducting normal interface. This behavior can vary from the case of a pure metallic interface to one in which there is a tunnel barrier, and an important factor is whether the energy of the electrons in the normal metal is higher or lower than the energy gap. The Blonder-Tinkham-Klapwijk theory—involving a neat mixture of charge imbalance (the origins of which are discussed by John Clarke in the following section) and a process known as Andreev reflection—accounts beautifully for all these possibilities and is widely used today. Subsequently, Mike, Greg Blonder, Teun Klapwijk, and Miguel Octavio extended this theory to account for the subharmonic energy-gap structure that occurs in superconducting metallic weak links, thereby elegantly explaining a phenomenon that had been a mystery for decades. In one of his last (and most often cited) papers, Mike and graduate student Sergio Valenzuela applied the concept of charge imbalance (see next section) to spin imbalance as it arises in the spin Hall effect.

Superconductivity and charge imbalance

I (JC) first met Mike and Mary in 1968 at the Low Temperature Conference (LT-11) in St. Andrews, Scotland, but it was not until the spring of 1972, when we were all on sabbatical leave at the Royal Society Mond Laboratory at the University of Cambridge, England, that I got to know them well.

At Berkeley, in the autumn of 1971, I had carried out some experiments on superconductors involving tunnel junctions. The essential idea was to inject electrons from a normal metal film into a superconducting tin film via a tunnel junction. On the other side of the tin film I deposited a second normal metal film, also with a tunneling contact. I could measure any voltage that appeared on this second normal metal—relative to a distant part of the tin film—by using a voltmeter based on a SLUG (superconducting low-inductance undulatory galvanometer), a kind of SQUID. To my great surprise, the measured voltage increased as I raised the static current in the first junction. This was quite unexpected, given that superconductors were not supposed to support a static voltage. I measured the dependence of this voltage on the applied current and on temperature in considerable detail. Clutching my brand new data, I flew off for my sabbatical leave.

I was delighted to learn that I would be sharing an office with Mike. As soon as we were settled in, I said, “Mike, I have new data that I think will interest you.” Mike replied, “I’m really sorry, but I am here to write my book [*Introduction to Superconductivity*], and I am already behind.” As a result, I continued to work away at my data all by myself.

Mike and I got in the habit of having lunch together—usually at the famous Eagle Pub, just 100 yards from the Mond Laboratory—complemented by half-pints of ale. I would then regale him with my latest failure to explain my data. One day, he finally gave in and said, “OK John, I’ll take just one afternoon—and only one—to look at your data.” I took him up on his offer that very afternoon, and, to make a long story short, Mike spent the next two months working out the underlying theory in great detail. He showed that under these non-equilibrium conditions a voltage arose from the imbalance between so-called “hole-like” and “electron-like” quasiparticles both above and below the Fermi surface of the superconductor. Needless to say, Mike’s theory fitted my data like a glove. We christened this phenomenon “charge imbalance.” Subsequently, several theorists picked up on the theory of charge imbalance, but I have to say that to me, Mike’s theory had the greatest degree of physical insight and the clearest explanation. As a postscript to this episode, Mike’s efforts on the theory of charge imbalance seriously delayed the writing of his book, as, with his usual good humor, he reminded me for years to come.

Mike, John Clarke, and Albert Schmid waiting for their lunch, Karlsrube, Germany, 1978. (Photo courtesy Rose Schempp.)

Mike and I revisited this subject, together with Albert Schmid, Gerd Schön, and Ulli Ecken, during a wonderful sabbatical leave in Karlsruhe, Germany, in the autumn of 1978. This was a particularly delightful sojourn in that John Bardeen and his wife Jane were also there for a couple of months. Mike, John, Albert, and I would have lunch together most days, an event that I found truly inspiring. As anyone who knew John remembers, he usually didn't say much. So Mike and I devised a plan to induce him to talk. After we had ordered lunch, Mike and I would take turns asking John some physics question that we had carefully planned beforehand, though most of the time he would not show the slightest sign that he had heard it. But then, usually during dessert—of which Mike was most fond—John would suddenly break into the discussion and deliver his answer. His great brain had simply been working it out while the rest of us chatted.

Mike and I learned a lot from Albert Schmid during our time in Karlsruhe. After lunch, Mike, Albert and I would retire to the institute coffee room for an incredibly strong, black coffee. Albert was utterly brilliant, but sometimes we found that his answers were so discursive that we weren't quite sure how to interpret them. So Mike and I came up with a plan by which Albert's answer would have to be "yes" or "no". So we asked our question and Albert duly replied. Subsequently, Mike and I retired to his office, where Mike turned to me and said, "Ok John, was that 'yes' or 'no'?"!

On a personal note, that autumn of 1978 in Karlsruhe was very special for me in that I spent a lot of time with Mike, Mary, and their sons Jeff and Chris. We visited various vineyards in the Schwarzwald, often accompanied by Gerd and his wife, where we all learned to appreciate Riesling. We visited Strasbourg, both for the cathedral and for the food. And I visited the Tinkham home, where I learned to appreciate Mary's fantastic dinners and the family's closeness and hospitality; I remember especially our joyous celebration of Chris's 10th birthday.

Mike plays his piano.
(Photo courtesy Jeff Tinkham.)

Simply a fine person

Mike was brilliant but also deeply humane. He taught fairness, integrity, and ethics by example. He had a wry sense of humor. He had warmth that engendered those around him to be affectionately irreverent. Two classic anecdotes illustrate this quality.

IFS remembers Mike once walking into the laboratory where the students had lunch and becoming very upset because we had built lock-in amplifiers, temperature controllers, etc., but none of the electronics was labeled. He demanded that we label everything in the lab. The next day he walked in and all five of us had our heads down while he examined the labeled apparatus. He then asked us to look up, only to see foreheads labeled Graduate Student.

MRB remembers how student after student would come out of Mike's office stunned at what had just happened. They went in thinking they had nothing in their experimental results but left with quite the opposite feeling. At a celebration at Harvard in honor of Mike, I observed that you could present data to Mike that you thought were pigeon droppings and leave believing you had flakes of gold. This irreverent remark was met by a chorus of "Yes!" from former students and postdocs present in the audience.

Mike retired from Harvard in July 2006, but he continued to be involved in physics as an emeritus professor. In the summer of 2008, Mike and Mary moved to Portland to be close to their children and grandchildren. He returned to Harvard for a visit in April 2009 to give the Lee Historical Lecture on "The Discovery of the Superconducting Energy Gap." By all accounts, it was brilliant and delivered in his inimitable style. The lecture was videotaped and is available online at http://media.physics.harvard.edu/video/?id=LEE_TINKHAM_041609).

Mike had a long, productive, and happy life, and enjoyed worldwide acclaim for his science. At home, he was a wonderful husband, father, and grandfather. He had great appreciation of good food and wine. He loved music and singing, and enjoyed traveling to many parts of the world.

Mike died of complications of a stroke in Portland on November 4, 2010. He leaves a legacy of scores of students and postdocs, many of whom have gone on to make their own marks on the world. He left as well an enduring collection of papers and books—notably Introduction to Superconductivity, which to this day remains the principal source for scientists and engineers for learning the basics of superconductivity.

ACKNOWLEDGMENT

The authors are deeply indebted to Mary Tinkham for providing us with details of Mike's early life and the first three photographs.

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