TT 20: Focused Session: 50 Years of Flux Quantization

Time: Tuesday 10:30–13:10 Location: HSZ 03

Invited Talk TT 20.1 Tue 10:30 HSZ 03
The discovery of fluxoid quantization: 2e or not 2e — •Dietrich Einzel — Walther-Meißner-Institut, D-85748 Garching

The year 2011 is quite remarkable because it allows us to celebrate not only the centennial of the discovery of superconductivity by Heike Kamerlingh–Onnes in 1911 but also the half–centennial of the discovery of what is referred to as *fluxoid quantization* in superconductors by Robert Doll and Martin Näbauer and, independently, by Bascom S. Deaver Jr. and William Fairbank. The experimental proof of the quantization of magnetic flux (or more accurately fluxoid) in hollow superconducting cylinders actually supports two important theoretical concepts, namely the pairing hypothesis formulated in the BCS theory of superconductivity and the concept of macroscopic phase coherence of the pair condensate. This talk is devoted to a discussion of the physics behind the Doll–Näbauer Deaver–Fairbank discoveries and is intended to review historically the chain of events which motivated these talented experimentalists and which led to their independent discoveries at quite remote points of the earth.

Invited Talk TT 20.2 Tue 11:00 HSZ 03
Fluxoid Quantization and the Superconducting Quantum Interference Device — •John Clarke — University of California, Berkeley CA USA

The observation of fluxoid quantization by Doll and Näbauer and by Deaver and Fairbank in 1961 and the observation of Josephson tunneling by Anderson and Rowell in 1963 laid the foundation for the demonstration by Jaklevic, Lambe, Silver and Mercereau in 1964 of quantum interference between two Josephson junctions interrupting a superconducting loop. Early types of SQUIDs (Superconducting Quantum Interference Devices) are briefly reviewed. Today, most SQUIDs are fabricated from thin films on silicon wafers in a square washer design, and are based on Nb-AlO$_x$-Nb tunnel junctions. Two applications of SQUIDs are briefly described. The first is the use of a near-quantum-limited SQUID amplifier in a detector to search for the axion, a candidate particle for cold dark matter. This amplifier potentially increases the axion search rate by as much as three orders of magnitude compared with a semiconductor amplifier. The second application is the use of a SQUID to detect the signal in an ultralow field magnetic resonance imaging (ULFMRI) system operating at 5.6 kHz. At this frequency, there is a significantly higher contrast between different tissue types compared with conventional MRI. ULFMRI may have applications in imaging cancer.

10 min. break

Invited Talk TT 20.3 Tue 11:40 HSZ 03
Flux Quantization driving Fractional Flux Quantum Generation — •Hans Hilgenkamp — University of Twente and Leiden University, The Netherlands

The single-valuedness of the superconducting wave function has peculiar consequences in ring structures in which phase-shifting elements are introduced. It namely demands that such phase-shifts are compensated to an integer multiple of 2π, for which the spontaneous generation of a corresponding/complementary fraction of a magnetic flux quantum by the ring is one possible option.

For example, in rings containing an element with a phase-shift of π, a spontaneous flux of a half the regular flux quantum is to be expected as the energetic ground state. This half flux quantum can have either up or down polarity, mimicking in a way the electron spin in a macroscopic structure.

This remarkable effect was key to proving the d-wave symmetry of the high-T$_c$ superconductors, in the famous Tsuei-Kirtley tricrystal ring experiment in the early 1990's.

By connecting high-T$_c$ superconductors with their s-wave low-T$_c$ counterparts it became possible to generate and couple a multitude of fractional flux quanta on a single chip. Similar developments are taking place using other forms of phase-shifters, such as Superconductor-Ferromagnet-Superconductor Josephson junctions. Besides for basic studies, such spontaneous-flux generating structures have proven to be of interest as new building blocks for superconducting (quantum)-electronics.

Invited Talk TT 20.4 Tue 12:10 HSZ 03
Quantum information with quantized fluxoids: flux qubits — •Johan E. Mooij — Kavli Institute of Nanoscience, Delft University of Technology

A closed superconducting ring which contains one or more Josephson junctions can exist in a quantum superposition of two states with different fluxoid number, when it is biased near half a flux quantum. The ring behaves as a two-level system and can be manipulated with microwave pulses. With three or four junctions in the ring, the size can be as small as several micrometers. The level splitting can be tuned with the applied magnetic flux, in addition one of the junctions can be converted into a SQUID leading to tunable quantum coupling between the fluxoid states . Relative to other types of superconducting quantum bits, flux qubits have the advantage that the next-higher level is separated by a high energy. Quantum operations can be performed in nanoseconds, coherence times go up to microseconds. Readout is performed with a SQUID that senses the generated flux of order 0.001 flux quantum. Inductive coupling between qubits is typically h times 200 MHz, allowing the realization of quantum entanglement. With flux qubits it is possible to achieve ultrastrong coupling between a two-level system and a harmonic oscillator.

Invited Talk TT 20.5 Tue 12:40 HSZ 03
Flux quantization and the quantum Hall effect — •Klaus von Klitzing — Max-Planck-Institut für Festkörperforschung, D-70569 Stuttgart

The combination of electrons with flux quanta is an important ingredient for discussions of phenomena related to quantum Hall physics. Especially the introduction of composite fermions (an electron accompanied by an even number of fluxes) is very successful in discussing the fractional quantum Hall effect on the basis of the integer quantum Hall effect. The talk summarizes experimental phenomena in quantum Hall physics where the flux quantization plays an important role.