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QnAs with John Clarke

Farooq Ahmed
Science Writer

More than five decades after superconductivity was discovered, John Clarke's graduate adviser, Brian Pippard, at Cambridge University proposed a novel device to measure minute voltages. Clarke, now a Professor of the Graduate School in the Department of Physics at the University of California, Berkeley, constructed such an ultrasensitive voltmeter based on a superconducting quantum interference device (SQUID). In the ensuing half-century, he has worked on both experimental and theoretical aspects of SQUIDs and applied them to a wide variety of applications, including charge imbalance in superconductors, MRI, cold dark matter and galaxy clusters, and quantum bits (qubits). SQUIDs rely on the phenomenon of Josephson tunneling, in which a pair of electrons tunnels through an insulating barrier from one superconductor to another. A SQUID—two Josephson junctions connected in parallel on a superconducting loop—is a sensitive detector of magnetic flux. PNAS recently spoke to Clarke, who was elected a foreign associate of the National Academy of Sciences in May 2012, about his current SQUID research.

PNAS: You have developed an MRI machine that can image human volunteers using magnetic frequencies four orders of magnitude lower than conventional machines. Why is this significant?

Clarke: There are a couple of reasons. Clinical MRI machines are expensive, heavy, and use large superconducting magnets. Our ultralow-frequency MRI (ULFMRI) machine could be built less expensively because it does not require a large magnet and is relatively lightweight.

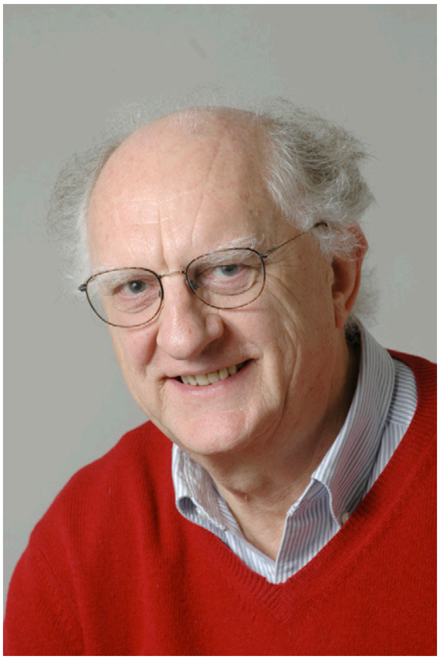
From a technical point of view, low frequencies provide greater contrast between different tissue types. We studied surgically removed prostate tissue and found a contrast between healthy and cancerous tissues not found at high field. Our technique might also extend to other types of cancer, and we are currently studying ex vivo breast tissue. Eventually, we hope to be able to image tumors in vivo. In our Inaugural Article (1), we combined two MRI techniques, inversion recovery and spin echo pulse sequences, to image the brain of human subjects. We could, at will, selectively enhance brain tissue, cerebrospinal fluid, or blood in the superior sagittal sinus, the large blood vessel at the top of the head. Needless to say, clinical high-field MRI that is currently in use is quite marvelous. We will need to speed up our ULFMRI machine significantly to make it clinically useful.

PNAS: Your interest in SQUIDs has led you to pursue applications in a variety of scientific disciplines. What has driven the diversity of your work?

Clarke: Technological need drives invention. The axion detector is a particularly good example. Axions are proposed elementary particles that may compose the cold dark matter that pervades the universe. The question is: how do you find this particle, which if it exists, is extremely light and of unknown mass? In the presence of a large magnetic field, the axion is predicted to decay into a photon with a frequency determined by the axion mass. This idea led to ADMX—Axion Dark Matter eXperiment—now at the University of Washington, Seattle. ADMX consists of a person-size electromagnetic cavity cooled to near-zero temperatures and surrounded by a large superconducting magnet. The cavity contains an antenna followed by an amplifier to detect the photons. The first-generation ADMX involved a semiconductor amplifier, but the predicted time to observe an axion was unrealistically long. A quantum-limited SQUID amplifier gives one hope of observing the axion—if it exists—in 1,000th of the time.

PNAS: You have also been involved in a search for galaxy clusters. What is the connection to SQUIDs?

Clarke: The last two decades have seen an extraordinary advance in our understanding of the origin of the universe, much of it from observations of the Cosmic Microwave Background. The most sensitive detectors of this radiation are transition edge sensors (TESs). The absorption of a photon produces a tiny change in temperature that gives rise to a large change in TES resistance. Needless to say, this change is detected by a SQUID. Because one would like 1,000 or more TESs on a given telescope, collaborators at University of California, Berkeley, Lawrence Berkeley National Laboratory, and I worked out a multiplexing scheme to read out a group of TESs with a single SQUID. Using multiplexed TESs, the South Pole Telescope in Antarctica discovered many hundreds of previously unknown galaxy clusters.



John Clarke. Image courtesy of Peg Skorpinski.

1 Inglis B, et al. (2013) MRI of the human brain at 130 microtesla. *Proc Natl Acad Sci USA* 110:19194–19201.

This is a QnAs with a recently elected member of the National Academy of Sciences to accompany the member's Inaugural Article on page 19194.

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