What's the noise eating quantum bits?

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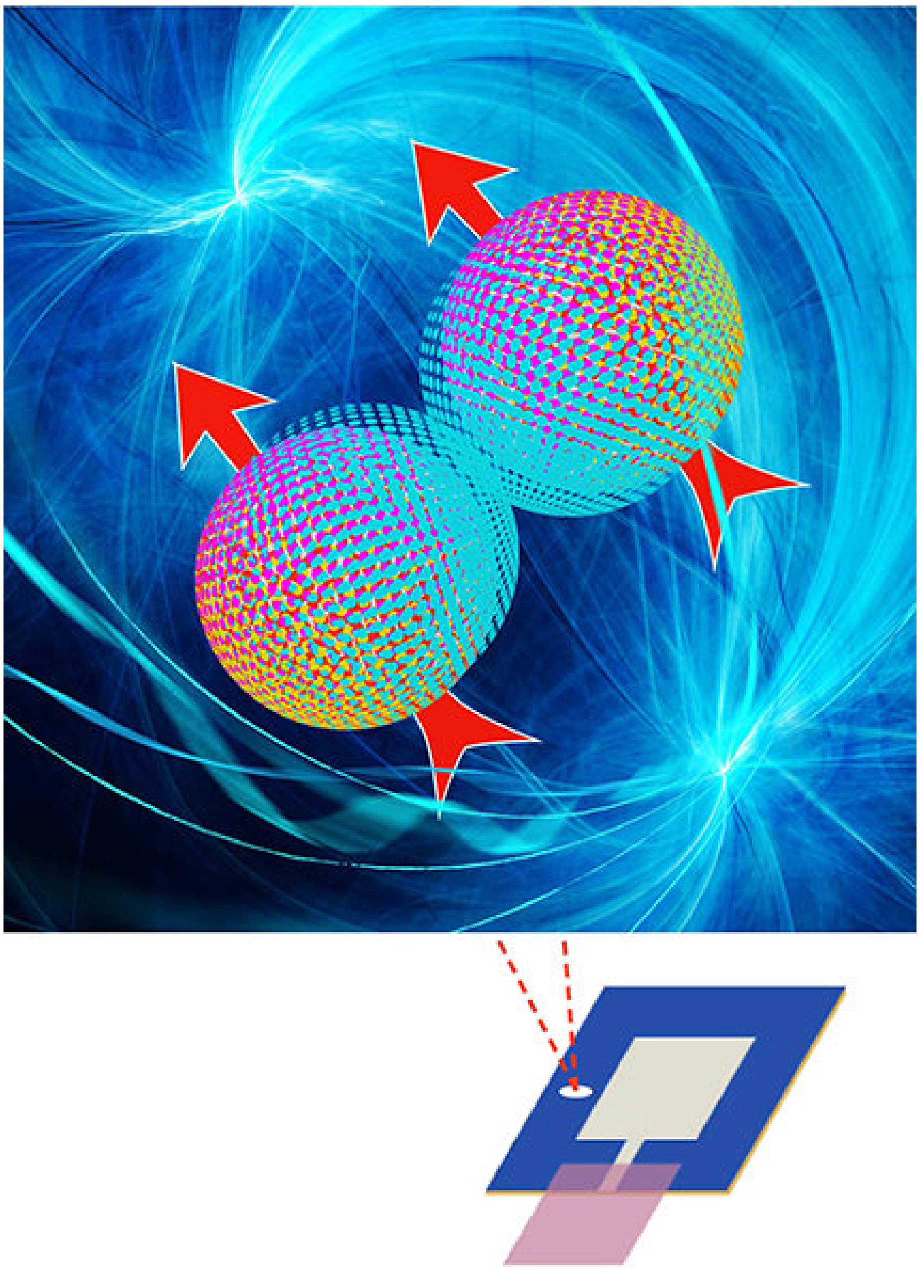

Noise is an obstacle in the race to realize systems that can be used to develop quantum computing technologies. Among the approaches for quantum computing is the superconducting quantum interference device (SQUID), shown at the bottom of the figure. Researchers have shown that the main source of noise is magnetic defects on the SQUID. These defects are produced by molecular oxygen (O2) adsorbed on its surface. The artistic drawing is of magnetic noise from molecular oxygen. The sketch shows twisted magnetic field lines induced by harmful fluctuating magnetic spins (arrows) of O2 (spheres) on the surface of a SQUID quantum bit. Credit: US Department of Energy

Super powerful quantum computing relies on quantum bits, aka qubits, which are the equivalent of the classical bits used in today's computers. SQUIDs are being investigated for the development of qubits. However, system noise can destroy the data stored in the resulting qubits. Calculations have confirmed experimental evidence that oxygen molecules adsorbed on the surface of the SQUID are the most likely source of low-frequency magnetic noise. Scientists identified mitigation strategies, such as surface protection and improved vacuum environments. These approaches lowered the surface oxygen and the associated noise to levels needed for SQUIDs to be used in the next generation of computers.

Superconducting devices are candidates for developing qubits. One type of device is called a SQUID for superconducting quantum interference device. It is based on a superconducting loop containing one or two Josephson junctions and allows measurement of quantized magnetic energy. However, the ability to develop SQUID-based quantum computers will require the stored magnetic data survive for long times. Scientists discovered the origin of magnetic noise in these systems, and ways to minimize it. Their work provides a design strategy for the development of tunable superconducting qubits with long lifetimes.

In quantum computing, quantum information is lost due to a loss of synchronization (dephasing) in the electronic flow and energy relaxation. Magnetic flux noise is a dominant source of dephasing and energy relaxation in superconducting qubits. Recently reported experiments indicated that the detrimental noise is from unpaired magnetic defects on surfaces of superconducting devices. Theoretical predictions singled out oxygen as the cause of noise in these systems. In a team effort, theory calculations at the University of California, Irvine and experimental measurements by their collaborators showed that adsorbed molecular oxygen (O2 on the surfaces is the dominant contributor to magnetic noise for superconducting niobium and aluminum thin films.

The mechanism is related to the outermost electrons of the oxygen molecule forming a magnetic spin-1 triplet state. Theory and experiment were iterated to find mitigation strategies. Surface treatment with ammonia and improving the sample vacuum environment dramatically reduced the surface contamination (to less than one oxygen molecule per 10 nm2), minimizing magnetic noise. In x-ray experiments at the Advanced Photon Source, scientists measured the suppression of magnetic spin and magnetic noise. Molecular oxygen was confirmed as the extrinsic noise source. The identification of this source explains the weak dependence of this type of noise on device materials.

Also, discovering the origin of this noise invalidates prevailing theories for the noise based on defects at the metal-insulator interface. Suitable surface protection and improvements in the vacuum can lead to significant reductions in low-frequency magnetic noise. This new understanding of the origin of magnetic flux noise could lead to frequency-tunable superconducting qubits with improved dephasing times for practical quantum computers.

More information: P. Kumar et al. Origin and Reduction of 1/f Magnetic Flux Noise in Superconducting Devices, *Physical Review*

Applied (2016). DOI: 10.1103/PhysRevApplied.6.041001

Hui Wang et al. Candidate Source of Flux Noise in SQUIDs: Adsorbed Oxygen Molecules, *Physical Review Letters* (2015). DOI: 10.1103/PhysRevLett.115.077002

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