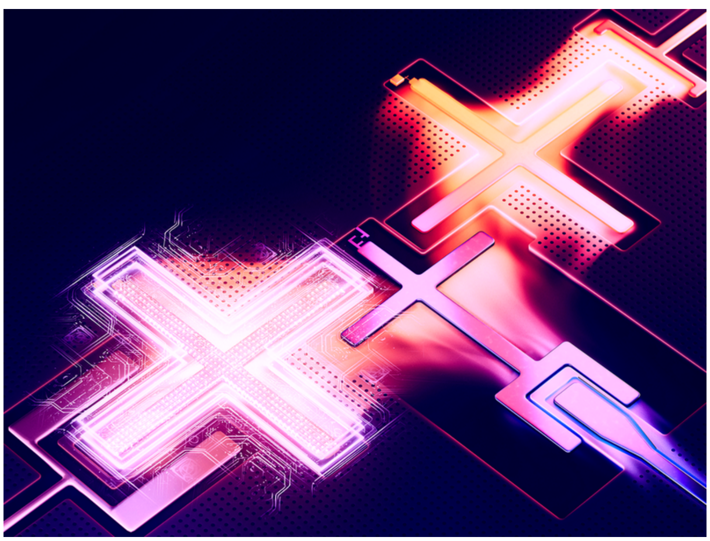
Quantum Refrigerator Keeps Qubits Cool

Physicists have demonstrated a quantum machine that could reduce errors in quantum computers by ensuring that the qubits they use remain in their initial state before a calculation starts.

By **Susan Curtis**

To produce accurate results, computational devices must start a new calculation from 0. This maxim is true for both classical and quantum devices, but it is harder to achieve for quantum computers, as extreme sensitivity to heat and radiation makes it difficult to preserve qubits in their initial state. Now Simone Gasparinetti and colleagues at Chalmers University of Technology in Sweden and Nicole Yunger Halpern and colleagues at the National Institute of Standards and Technology in Maryland have created a quantum refrigerator that could offer a solution to this problem for quantum computers that encode information in superconducting qubits [1]. The refrigerator can cool such qubits to a record low temperature of 22 mK, making it more likely that they remain in their initial state until a calculation begins.



The quantum refrigerator, seen here in an artist's conception, can cool a superconducting qubit to record low temperatures. The cooling device is made from two superconducting circuits that remove heat from the processing qubit (bottom left), ensuring that it is always primed for efficient quantum computation.
Credit: Chalmers University of Technology; Boid; NIST

Qubits made from superconducting circuits are one of the leading technologies being exploited in emerging quantum computers. At ultralow temperatures such superconducting circuits exhibit quantized energy states that allow researchers to encode the qubits in two distinct states: a ground state and an excited state. Each qubit can exist in one or other of these two states—like the bits in a conventional computer—or in a quantum superposition of the two. Putting qubits into superposition states allows a quantum processor to simultaneously examine many potential solutions to a problem, delivering a dramatic improvement in computational power over a classical computer.

At the beginning of a calculation, all the qubits should be in their ground state, which for superconducting qubits requires that the qubits be kept as cold as possible. However, even in the best cryogenics systems, the qubits can absorb heat from their environment. A small percentage of the qubits gain enough energy to switch to their excited state, introducing errors right at the start of the computation, which can lead to others as the calculation proceeds. As a result, more errors must be corrected to achieve an accurate result.

To address this problem Gasparinetti and colleagues have created a quantum refrigerator that extracts heat from the qubits by exploiting a temperature gradient, such as the one that exists within the cryogenics systems used to cool quantum computers. These systems consist of a series of stages kept at progressively lower temperatures, with the coldest stage typically maintained at around 10 mK.

The team's quantum refrigerator consists of two qubits: a "hot" qubit that is connected to a heat source kept at around 5 K and a "cold" qutrit—similar to a qubit but with three quantized energy levels—that is connected to the coldest part of the cryostat. The energy gaps of the hot qubit and the cold qutrit are carefully tuned to those of a third "processing" qubit—the one involved in the calculations—enabling the transfer of heat between them. If the processing qubit gets excited, its energy combines with a quantum of thermal energy from the hot qubit to excite the cold qutrit into its highest energy level. As part of this energy exchange, the processing qubit is reset back to its ground state, priming it for the start of a new calculation. The energy from the excited qutrit also drains away to the cryostat, resetting it back to its lowest energy level.

When used to cool a single superconducting qubit, the researchers showed that their approach could reduce the qubit's effective temperature to 22 mK. That drop reduces the probability that the qubit becomes excited to below 3×10^{-4}, compared with around 10^{-3} for today's superconducting quantum computers. They also showed that the extra cooling power provided by the refrigerator could speed up the initialization process, with an excited qubit relaxing back to its ground state 70 times faster than if the qubit is cooled only by the cryostat. "This increase [in speed] could lead to faster quantum computation, as the reset time is the most time-consuming step in a quantum algorithm," says Michele Campisi, a physicist working in quantum thermodynamics at the CNR Institute of Nanoscience in Pisa, Italy, who was not involved with this work.

While the design of the quantum refrigerator would need to be expanded to cool all the qubits in a quantum computer, this proof-of-principle demonstration shows how quantum thermodynamics could be exploited to drive a key function in quantum information processing. "This work nicely illustrates the crucial and lively role that quantum thermodynamics currently plays—and will continue to play in the future—for the advancement of quantum science and technology," Campisi says.

The researchers now believe that their approach could also be used in other applications. "Running a refrigerator in reverse amounts to running an engine, and one possible use of such an engine is to power an autonomous quantum clock," Yunger Halpern says.

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REFERENCES

1. M. A. Aamir *et al.*, "Thermally driven quantum refrigerator autonomously resets a superconducting qubit," **Nat. Phys. (2025).**