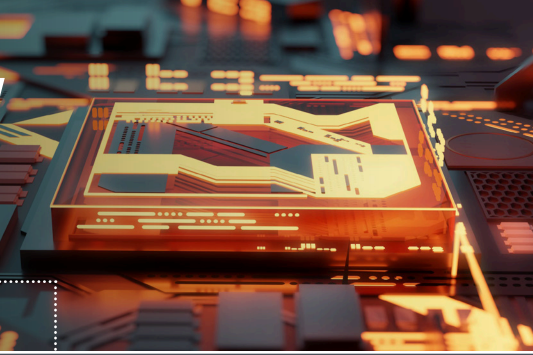
Quantum Science & Technology

University of Colorado Boulder



Quantum 2.0

Quantum information science and engineering is at a tipping point. Researchers exploring the farthest edges of classical physics are beginning to tap into the fundamental laws of the quantum world to open new frontiers of possibility. Drawing on quantum entanglement, investigators are poised to drastically improve the acquisition, processing and transmission of information.

At the same time, **advances across quantum science** are combining to transform laboratory demonstration into technological reality. This leap from the lab to real-world impact requires an environment that drives fundamental advances, develops engineering and technical expertise, provides enabling infrastructure, cultivates the next generation workforce, and supports integration with the private sector.

CUbit
QUANTUM INITIATIVE

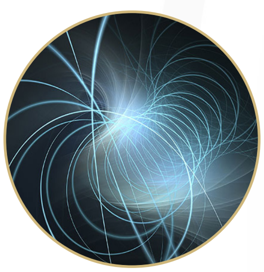
The **CUbit Quantum Initiative** coordinates quantum activities at CU Boulder, catalyzing focus areas and research centers across the university.

Focus Areas

Quantum 2.0 will advance through key focus areas that share common technological threads:

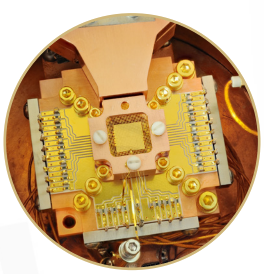
Quantum Sensing and Measurement

Quantum sensing is critical to high-impact, practical application of Quantum 2.0 because it directly benefits from, verifies, and has applications in quantum information science. With four Nobel Prizes combined, CU Boulder, NIST and their jointly managed research institute JILA have a distinguished history of developing and exploiting increasingly precise sensing and measurement techniques. With further stimulation from Quantum 2.0, researchers will open new opportunities for major science and technology breakthroughs, including searches for new physics and navigation without GPS.



Quantum Networks and Communications

Interconnected quantum systems form a quantum network. For example: quantum bits in the form of individual atoms can be interconnected with individual photons for remote entanglement. Building a scalable quantum machine requires robust quantum communication channels. Development of high-efficiency and high-fidelity protocols to transmit and store quantum information over macroscopic distances will enable the first realizations of quantum networks with long-distance quantum communication and non-local quantum sensing applications.



Quantum Computing and Simulation

The power of quantum computing resides in the subtle interplay between the unique resources of superposition and entanglement of many quantum bits. Superposition creates quantum parallelism, while entanglement is used for quantum operations. Together, they can address and manipulate many quantum particles to potentially achieve exponential speed-up over classical computers. While general-purpose quantum computers are still far in the future, small-scale, programmable quantum systems can already run quantum algorithms and simulate complex quantum phenomena, novel materials and chemical activity.

Quantum Science and Technology Research Centers

Quantum Systems through Entangled Science and Engineering (Q-SEnSE) is a **Quantum Leap Challenge Institute**, initially funded by NSF and led by CU Boulder in partnership with seven universities, three national labs and NIST. Prominent quantum researchers collaborate to explore how advanced quantum sensing can reveal new fundamental physics, develop and apply novel quantum technologies, provide tools for a national quantum sensing infrastructure, and train a quantum-savvy workforce.

Q-SEnSE organizes its research agenda into three Grand Challenges pursuing quantum science and engineering projects with high potential impact in fundamental science or practical application:

- Ultra-precise Sensing and Measurement with a Quantum Advantage
- Engineering Principles Applied to Quantum Information Science
- National Infrastructure for Applications in Quantum Sensing (with strontium as a pilot case)

The **Quantum Systems Accelerator (QSA)**, initially funded by DOE, is a multiorganization initiative established to design and deliver scalable quantum computers within five years. The QSA includes CU Boulder researchers from JILA/Physics and NIST with expertise in quantum sensing, quantum transduction and quantum computer simulation. CU Boulder projects are: **Advancing Systems for Quantum Information Science**, and **Programmable Quantum Systems** for applications such as computing, simulation and sensing.

Five-year goals for the **QSA** include:

- Demonstrate individual universal quantum control of more than 50 ions
- Design and implement quantum algorithms for high-level quantum computing and simulation
- Demonstrate entangled many-body system with more than 1,000 atoms

The **Joint Quantum Engineering Initiative (JQEI)** is a nascent center in which faculty from the College of Engineering & Applied Science and scientific staff from NIST Boulder Labs establish and operate a lab cluster at CU Boulder. JQEI is partly modeled on JILA, the highly successful CU Boulder-NIST joint institute. By merging engineering approaches with quantum physics innovations at the earliest stages, JQEI empowers research and development to deliver **quantum innovations for adoption by industry and use in society**.

JQEI brings together scientists and engineers in a dedicated space at CU to work on:

- Next-generation field-deployable ultra-stable clocks
- Translation of quantum sensors into real-world systems and networks
- Engineering student engagement in quantum science

Quantum Forge is a **hands-on student training experience** providing a novel laboratory space for multidisciplinary teams of undergraduate and master's students from engineering and physics. The result: developing research, communication and problem-solving skills while addressing challenges identified by companies and Q-SEnSE investigators. Teams will calibrate, characterize, build and design technologies relevant to a research lab, so graduates can enter the workforce ready to participate in and contribute to practical problem-solving in a quantum setting.

The **Quantum Forge** curriculum includes:

- Introductions to laboratory-relevant test equipment
- Fabrication skills (including electronics and machining) with integration into existing shops
- Fundamental quantum concepts, such as qubit rotations on the Bloch Sphere

Center Focus Areas

	Q-SEnSE	QSA	JQEI	Quantum Forge
Quantum Sensing and Measurement	✓	✓	✓	
Quantum Networks and Communication	✓			
Quantum Computing and Simulation	✓	✓	✓	
Student Hands-On Training in Quantum	✓	✓	✓	✓
Translational Engineering & Entrepreneurship			✓	

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