Written testimony of

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Before

The United States Senate Committee on Commerce, Science, and Transportation

Hearing on

“Securing U.S. Leadership in Emerging Compute Technologies”

September 29, 2022

ColdQuanta

Chairperson Cantwell, Ranking Member Wicker, and Members of the Committee, thank you for the opportunity to speak with you today on behalf of the ColdQuanta corporation regarding our nation's leadership position in quantum computing and other emerging quantum technologies.

The bottom line

I will start with the bottom line: quantum technology and computing will fundamentally and profoundly change how we live and do business. It has the potential to transform completely our economy, national security, and the daily lives of all Americans, including discovering new medicines, engineering better batteries, and creating many new jobs.

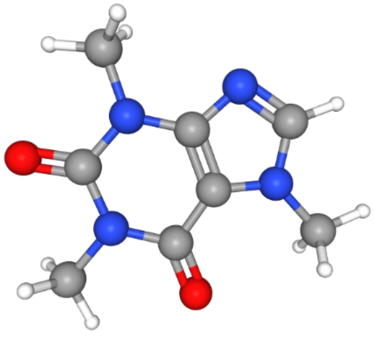
There is a global quantum race happening. We are not the only country that recognizes the potential of quantum technology. If we do not make new strategic investments and organize more effectively at the federal level to accelerate the domestic development of quantum, we could lose.

Science, not fiction

Based on my experience in the quantum industry, I want to share with you how revolutionary quantum information science and technology are.

The word "quantum" may conjure up thoughts of science fiction, with television shows such as *Quantum Leap* and movies like *Ant-Man and the Wasp* bringing the "quantum realm" into popular culture. Luckily for us, technologies like quantum computing, quantum inertial sensors, quantum radio-frequency receivers, and atomic clocks are anything but fiction.

To give you a realistic example of what quantum computing is capable of, let's consider the field of chemistry. In this area, we expect to see many impactful quantum computing applications. We base quantum computing on the principles of quantum mechanics, which explains the behavior of atoms, electrons, and photons (or particles of light). Modeling chemical behavior at the atomic level is notoriously difficult and slow, and it is often necessary to sacrifice the accuracy of the solution to get an answer in a reasonable amount of time, even with massive computer resources.



The caffeine molecule

A molecule that most of us are intimately familiar with is caffeine. Though caffeine has a notable effect on us, it is a small and relatively simple molecule. Surely we should be able to model on a computer how caffeine operates on our brain to keep us awake and alert. Using a classical computer, we represent information with bits, or zeros and ones. However, to perfectly represent a single caffeine molecule in a classical computer, we estimate we would need

$$10^{48} = 1000000000000000000000000000000000000000000000000$$

bits of information. For comparison, scientists estimate that if you counted up the entirety of the atoms in the earth, every rock and human and molecule of air or drop of water, that number is between 10^{49} and 10^{50}.

So to model just one caffeine molecule with a classical computer, we would need an amount of storage comparable to 1 to 10% of the size of the earth. We will never see this with the classical computer technology we use today.

The promise of quantum computing

Quantum computing can do better. Through the quantum mechanical properties of "entanglement" and "superposition," quantum computing promises to solve problems that classical computers could never hope to do in our lifetimes (or our great, great, great grandchildren's lifetimes). In quantum computing, we use "qubits" or "quantum bits" instead of bits. We expect to be able to represent caffeine using only 160,000 qubits. With quantum computing, we could develop new medicines, antibiotics, and antiviral drugs and design new and much more efficient lithium batteries for transportation. If we could discover new catalysts for creating fertilizers, we could have far more sustainable processes supporting agriculture that use much less energy. And we could find new alloys and materials for aerospace, automotive, and military use.

However, it is essential to note that quantum computers are in the early stages of development. How large are the qubit counts of quantum computers we know of today using public information? These range from single digits to slightly more than 100. In 2021, a team from the University of Science and Technology of China announced that they had built a 62-qubit computer.[1]

Quantum computing intersects with cybersecurity because it may be possible someday to break several kinds of encryption methods we use today. A recent estimate puts the necessary qubit count for a successful attack at approximately 20 million.[2] In July, the United States National Institute of Standards and Technology announced four new "quantum-resistant" cryptographic protocols that should withstand attack via future quantum computing systems.[3]

Taking quantum to the Edge

I believe many people make the mistake of only thinking of "quantum supercomputers" living in data centers, taking up a lot of room, and having significant energy requirements. If there is one thing we have learned over and over in the nearly 80 years of the modern computing era, computers get smaller and more powerful. We put more of them in places we did not expect. Your smartphone might have been a supercomputer 30 or 40 years ago. We must consider computing and data at the Edge.

Astronaut Christina Koch with NASA's Cold Atom Lab and ColdQuanta technology "at the Edge" aboard the ISS.

Edge computing works with data close to where it is created or used. We might put a quantum computer in a cell phone tower or factory. We will want significant processing capabilities on planes, ships, submarines, and perhaps even satellites. We cannot always bring information back into a data center.

In military situations, we may not be connected to centralized computing resources. We expect to use quantum computers for AI and optimization problems like logistics. One of the areas of great interest at the Edge is federated or distributed machine learning for AI applications.

The United States must invest in scaling up the power of quantum systems while scaling down their size and cost for use at the Edge. A "data center-only" strategy may leave us vulnerable to not having the compute resources we need where we need them.

The start of the marathon

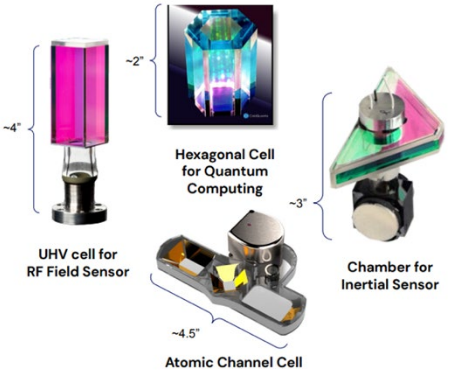
These systems require significant investment, scientific progress, engineering innovation, education, and skills development to bring into being. We should not wait. If we hesitate or under-invest, other nations could take the lead in creating and using these technologies for commercial and military applications. Through legislation like the CHIPS Act and the earlier National Quantum Initiative, Congress and the White House have already taken important steps to begin to secure our quantum future. More is needed. We need to accelerate the development of this technology and do this in parallel with building a robust domestic supply chain and workforce.

The race is on, but we have a long way to go to perfect usable quantum computers. We must rapidly scale these systems to make them usable.

Other types of quantum technology—such as quantum inertial sensors, quantum radio-frequency receivers, and atomic clocks—are much closer to becoming fieldable devices. These have the potential to protect against GPS denial and improve intelligence gathering with high sensitivity receivers in the next few years, not decades. Investments in these technologies will feed back into and accelerate our quantum computing development. My company, ColdQuanta, uses “cold atom” technology we have already deployed on the International Space Station with the Jet Propulsion Laboratory to build our qubits.[4] We expect systems based on cold atoms to scale up to the needed range.

Quantum sensors for the near term

“Quantum” has many other applications. Positioning, navigation, and timing, or “PNT,” concerns accurately locating ourselves and moving to where we need to be. Doesn’t GPS, the Global Positioning System, already give us this? News reports have stated that foreign powers have spoofed or denied GPS services to confuse and disadvantage their enemies at war. Quantum inertial sensors, including accelerometers and gyroscopes, and quantum atomic clocks, should be able to replace GPS, prevent spoofing, or act as a backup in case of local and catastrophic service failure.



ColdQuanta cold atom cells for several quantum applications.

Commercially, these can benefit transportation and logistics on land and at sea. From a defense and intelligence perspective, quantum sensors could provide required, stable, and accurate measurements for our use on land, at sea, and in space. Quantum gravity sensors could assist in finding new energy and mining resources and detect underground facilities not apparent from visual examination.

Work has begun to use quantum sensing as antennae for radio frequencies such as those used in communications networks and cellular devices. We believe we can eventually manufacture smaller and more sensitive receivers that allow us to use more of the radio spectrum. For example, a ship, plane, or troops on the ground could have more compact communications systems with broader connectivity. In the U.K., British Telecommunications has already started trials of quantum RF technologies to augment 5G and presumably incorporate into 6G eventually.[5]

While it may seem more straightforward to focus only on computing, quantum sensors provide the *data* we will need to incorporate into processing at the Edge for commercial, intelligence, and military use. The data has the advantage that it is already encoded in a manner usable by quantum computers.

Being in the proper format does not mean we can move data where needed. The United States must invest in quantum interconnect technology to link quantum computers, sensors, and memory. Without the interconnects, we will restrict ourselves to building systems that cannot scale big enough or use data for the practical applications I have described above.

As I said at the beginning of this statement, quantum refers to Nature's structure and behavior at the smallest levels. Quantum technologies operate at the best resolutions possible. There is no higher resolution to go to than the quantum scale. There is no "next time" to get this right, to invest more aggressively, for the results and leadership we must have.

The call to action for skills and components

In what I think is a massive understatement, quantum is not easy. Programming a quantum computer is unlike writing software for a phone, laptop, cloud server, or supercomputer. Just as we teach classical programming in high schools today, we must extend curricula to include quantum. We must strengthen our education in computer science, physics, mathematics, and engineering if we expect to have a national workforce with the necessary skills to build and use quantum tech. We have made a good start at quantum computing education, but this must accelerate. We must extend physics and engineering education throughout our university systems to translate the science of quantum sensors into practical and ubiquitous products.

While we always need some people with the most advanced degrees at the leading edge, the quantum workforce will not be limited to those with doctorates. Just as today, we will need trained workers in manufacturing, I.T., and software and hardware engineering. There will be many new jobs and types of jobs, and we must have a trained workforce to fill them.

We must also secure our domestic supply chain. For many quantum modalities like ColdQuanta's cold atoms, we need increased access to lasers and rapid evolution of photonic integrated circuits. We must drive down the cost and size of these components. Only then can the United States ensure it can build the computers and sensors it needs.

Ensuring successful government, academic, and commercial collaboration

We appreciate your legislative support to reorient federal spending and policy priorities to accelerate quantum development. Now is the time to guarantee we can execute the program. In particular, we require better procedural and program mechanisms to navigate the so-called "valley of death" stage of development, where we have scattered investment in and development of the pieces without integration into deployed systems of record.

From where will quantum innovation come? To date, it has grown out of academia and been prototyped for government agencies but has only been commercialized by industry to a limited degree. Software is vital to making the quantum hardware usable, so in May, we acquired Super.Tech, a startup spun out of the University of Chicago. We must strengthen and accelerate the academia-government-commercial collaboration to get practical and pervasive quantum technologies in the next several years instead of the next several decades.

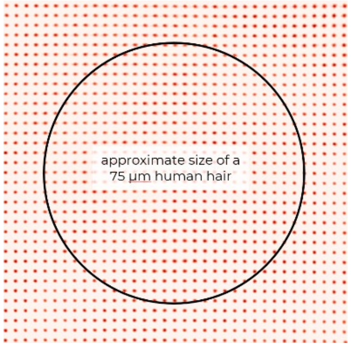


Image of actual ColdQuanta 1225 cold atom "pre-qubit" array at the University of Wisconsin

There is currently a shortage of federal assistance to help small quantum companies transition their promising cutting-edge technology now under development to prototyping and then to production scale and capability.

These are expensive steps that have sidetracked many promising advances in the past. We can't let that happen to the best-of-breed quantum projects now, given the stakes of losing to foreign adversaries. We need to do more to track, manage, and coordinate the many individual federal quantum R&D projects across the government. We must ensure gaps are understood and covered, the most promising technology is fast-tracked and well supported, and overlaps and duplications are removed.

Thank you for this opportunity to highlight the quantum technologies that will be most valuable to the United States and to offer my recommendations to secure our leadership.

I am happy to answer any questions you may have.

Qualifications – Dr. Bob Sutor

How can I be so sure that quantum will change the world as I describe it? I am a 40-year computer industry veteran. I have an undergraduate degree from Harvard and a Ph.D. from Princeton, both in theoretical mathematics. In 2017, I became part of the leadership team of the IBM Quantum program after leading the 300-person IBM Mathematical Sciences Department for six years. I am the author of the quantum computing book *Dancing with Qubits* and the classical-quantum software development textbook *Dancing with Python*. I am a frequent keynote speaker at industry conferences. I have been quoted and interviewed in the Washington Post, the New York Times, the Guardian, Barron's, USA Today, CNBC, and many other media outlets.

I moved to ColdQuanta in March after 39 years at IBM because I believe the value of quantum technology extends far beyond the data center.

At ColdQuanta, Inc., we trace our roots back to a collaboration between two brilliant minds: Albert Einstein and Satyendra Nath Bose. In 1924, Bose sent a letter to Einstein and respectfully asked for his help. This correspondence sparked their uncovering of a new form of matter, later named the "Bose-Einstein Condensate (BEC)." When we cool atoms to a few millionths of a degree above absolute zero, they begin to clump together, condense into the lowest accessible quantum state, and transition from a gas into a BEC. However, this was speculation, as the technology needed to create BEC wouldn't exist for another 70 years.

In 1995, Dr. Eric Cornell and Dr. Carl Wieman created the first-ever BEC in Boulder, Colorado, at JILA—a collaboration between the University of Colorado at Boulder and the National Institute of Standards and Technology (NIST). Drs. Cornell and Wieman won the Nobel Prize in Physics in 2001.

ColdQuanta was co-founded in 2007 in Boulder, CO, by Professor Dana Anderson, an academic colleague of Drs. Cornell and Wieman. Since then, the company has built atomic clocks and quantum sensors, often in response to requests from United States agencies, including NASA, DARPA, and the Departments of Defense and Energy. Over the last four years, we have started the development of a quantum computer under the scientific direction of Professor Mark Saffman at the University of Wisconsin, Madison. We are a global company focusing on the United States and the United Kingdom. Our offices are in Colorado, Wisconsin, Illinois, and Oxford, United Kingdom, with additional employees in New York, Texas, California, and Florida.

ColdQuanta is committed to delivering broad quantum advantage through direct research and development of a wide range of quantum technology in collaboration with government and academia. We have become, in many ways, the foundation of a quantum supply chain and ecosystem. We are the only United States manufacturer of many key components for cold neutral atom and adjacent quantum research. We have two hundred employees, over 80 of which have PhDs in physics, engineering, mathematics, and computer science. We have 23 United States patents and many patent applications we expect to become patents with high probability in the next 12 months.

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[1] https://thequantuminsider.com/2021/05/10/chinese-research-team-designs-builds-62-qubit-superconducting-quantum-computer/

[2] https://quantum-journal.org/papers/q-2021-04-15-433/

[3] https://www.nist.gov/news-events/news/2022/07/nist-announces-first-four-quantum-resistant-cryptographic-algorithms

[4] https://coldquanta.com/coldquantas-latest-ultracold-technology-heads-to-the-international-space-station/

[5] https://newsroom.bt.com/bt-trials-new-quantum-radios-to-boost-next-generation-5g--iot-networks/