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Quantum Science and Technology



PERSPECTIVE

The US National Quantum Initiative

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Michael G Raymer^{1,2} and Christopher Monroe^{3,4}

¹ Oregon Center for Optical, Molecular, and Quantum Science, University of Oregon, Eugene, OR 97405, United States of America

² Department of Physics, University of Oregon, Eugene, OR 97405, United States of America

³ Joint Quantum Institute, NIST/University of Maryland, College Park, MD 20742, United States of America

⁴ Joint Center for Quantum Information and Computer Science, NIST/University of Maryland, College Park, MD 20742, United States of America

Abstract

Quantum technology exploits the unique quantum features of superposition, entanglement, and fundamental metrology metrics in order to create new opportunities in secure communication, high-precision sensing, and revolutionary computers. Quantum technology may eventually underlie a whole new technological infrastructure, much as the semiconductor revolution changed everything in last half of the 20th century. This paper summarizes the motivations and goals for the National Quantum Initiative (NQI) in the United States, and describes some of the processes that led to the introduction and passage of legislation in the US Congress to create the NQI.

1. Introduction

This paper summarizes the motivations and goals for the National Quantum Initiative (NQI) in the United States, and provides a look into some of the processes leading to the introduction and passage of the NQI legislation. The National Quantum Initiative Act (H.R. 6227) was passed nearly unanimously by both houses of Congress and signed into law by the President on 21 December 2019. We begin with a brief overview of the emerging field of quantum information science and technology (QIST).

2. Quantum information science and technology

The lag time between fundamental physics breakthroughs and world-changing technological applications is typically measured in decades. Examples of early quantum technologies are atomic clocks and lasers, introduced in the 1950s and 1960s, several decades after the early formulations of quantum theory. Atomic clocks and lasers are typically governed by the properties of large collections of atoms largely acting independently.

A new generation of quantum devices is now being imagined and realized, in which states of individual quantum objects (e.g. atoms, electrons, photons) are controlled and manipulated in ways only dreamed of in previous decades. Quantum-state entanglement, viewed previously as a ‘spooky’ aspect of quantum physics that begs for a more complete theory, is now accepted as the essential mechanism by which much of quantum technology operates.

The new generation of quantum technologies can be categorized into three broad types: quantum communication, quantum sensing, and quantum computing. Quantum communication promises security of data and messages being transported across information networks. Without such improvements to data security, the Internet as we know it might cease to function in 15–20 years. Quantum sensing promises unparalleled precision and accuracy of probing quantities such as acceleration and rotation, and magnetic, electric and gravitational fields. Its applications range from biomedical research at the cellular level, to navigation in GPS-deprived environments, to prospecting from aboveground for minerals or buried infrastructure. Quantum computing promises the ability to solve certain computational problems that will always be intractable using even the fastest and largest conventional supercomputers. Examples include breaking encryption codes by factoring numbers into their primes, simulating the structure of complex

molecules or materials to accelerate new drug discovery or produce more efficient solar-energy harvesters, and optimizing a range of complex models from logistics and finance to pattern recognition.

While basic science provides the base of quantum technologies, these new technologies can return the favor to basic science. They offer the ability to discover and probe the fundamental structure and behavior of Nature with unprecedented sensitivity and accuracy. For example, special ('squeezed') quantum states of light are being deployed to further increase the already astounding sensitivity of laser-interferometric gravitational-wave detectors, opening new windows into far-away and long-past behaviors of the Universe. And quantum computers may catalyze the development of new materials and molecular function.

The very possibility of developing quantum technologies moved scientists to create a new field of research—quantum information science (QIS). While a conventional computer, data link, or sensor operates with 'classical information,' represented by bits, the new generation of technologies operates with 'quantum information' represented by qubits. Groups of qubits can be in entangled states. These kinds of states provide a larger 'playground' (state space) in which to process information, greatly increasing the abilities of these new quantum devices. In turn, the concepts of superposition and entanglement are also emerging as important for studying fundamental questions such as the ultimate fate of energy and matter trapped inside a black hole as it 'evaporates' over billions of years. As important, the central ideas of classical information theory developed in the 1940s have been updated to qubits, including the ability to encode qubits (in particular entangled states) that allows the correction of errors to enable qubit stability.

3. The emergence of QIST beyond the research lab

The science that now underpins QIST concepts was developed gradually in the years 1980 to the present in a worldwide effort, mostly unrecognized by the general public. It was not until 2016 or so that US politicians were made aware of the potential of quantum-information-based technology as an engine of national and economic security. Why did the US government begin considering a coordinated public investment in QIST? How did it come to pass that the Chair of the US House Committee on Science, Space and Technology, Lamar Smith of Texas, was able to declare proudly in the committee's hearing room that the quantum-science bill the committee was planning to introduce to the full House of Representatives would be perhaps the rare one in recent memory that was co-sponsored by every committee member, both Republican and Democrat?

The policy story begins in the US intelligence community (IC). When scientists in the National Security Agency recognized that the quantum-computer algorithm invented in 1994 by Peter Shor (Shor's factoring algorithm) could efficiently and quickly crack typical encrypted messages, they began a wide-ranging program to fund scientists throughout the US and beyond to explore the feasibility of building quantum code-cracking computers. Perhaps the question then was not how quickly can we build such a code-cracking machine, but was it even possible and if so, when? Throughout the decade beginning in the later 1990s, several well-funded IC and defense-related programs were initiated by the US government to explore these questions. A great many of the advances in QIS resulted from the ensuing funding of university and government researchers.

The research community has recently arrived at a conclusion that was far from obvious 20 years ago: there are no known physics-based barriers to developing quantum technologies. A consensus has emerged that we are about a decade or two away from having fully programmable quantum computers sophisticated enough to crack encrypted messages. At the same time, it has become plausible to think that code breaking is one of the *least* compelling reasons to push quantum technology forward. Rather, the combined capabilities of all the diverse forms of quantum technology—secure quantum communication, high-precision quantum sensing, and powerful quantum computing and simulation—have the potential to create a whole new technological infrastructure, much as the semiconductor revolution changed everything in the 1960s through the 1990s. And, as the semiconductor industry grew gradually, beginning with products such as miniaturized transistor radios and hearing-aid amplifiers, the new quantum technologies will necessarily go through an evolutionary period of development, with the lower-hanging fruit, such as quantum sensors and communication systems being plucked first, and gradually growing through quantum simulators to full-function quantum computers.

QIST can cut across almost all sectors of technology and industry, and even the broader economy. And it can produce useful, commercializable devices along its evolutionary path to maturity, not relying on a single-end use as a measure of its success.

4. Why should governments invest in QIST?

Government investment in QIST can create the scientific/economic ecosystem needed for QIST to make the difficult transition from the research lab to commercialization. Such a path has been seen historically in other sectors. A useful example is the development of the Internet. It was initially funded by the Advanced Research

Projects Agency (ARPA), a US defense agency, as a computer-science research project with the goal of enabling distant computers to interact. Following the ‘Mister Watson, come here’ moment of the first email, it became clear that a new form of human communication had been invented. Yet, industry did not rapidly adopt the new technology or capitalize it into a for-profit enterprise. Rather, the early Internet was funded for a decade by the government’s National Science Foundation (NSF) as the NSFNET, enabling scientists to quickly communicate with remote supercomputers and with each other. Around 10 years after the NSF adopted the Internet build-out, corporations began to see the commercial potential of large investments in the technology and its applications; the rest is history.

A robust QIST ecosystem would include the ability of companies to create quantum technologies according to well-defined technical standards. It would provide marketplaces for the technology and sources of the components needed to construct their products. It would create a pipeline of workers and researchers trained in QIST, propelling quantum theory and its applications out of university research laboratories and into the marketplace.

The defense and intelligence communities would benefit from the growing expertise in the public and private sectors, allowing them to acquire new quantum inventions and software products, and the know-how to engineer advanced systems for their own purposes.

5. What is needed to create a QIST ecosystem?

A QIST ecosystem will be created by integrated academic, industry and government groups working together. The necessary elements of such an ecosystem include large-scale facilities or research laboratories, a trained specialized workforce, industry standards for product development and specification, a supply chain of producers of support instrumentation and software relevant to QIST, and a reliable marketplace for QIST products. In addition, quantum software developers need to have access to state-of-the-art quantum computers to develop and test new quantum algorithms. Finally, new basic research is needed to uncover the best possible methods and applications for QIST.

Up to the present, QIS has not needed large-scale facilities or research laboratories such as the telescopes that support astronomy, the colliders that support high-energy physics, or the advanced light sources that support materials science. Now QIS is rapidly outgrowing its present incarnation as a science that can be done in small groups of graduate students, postdocs, and professors or small groups of industry scientists. While the small ‘tabletop’ experiments of the past 20 years have demonstrated the theoretical potential of technologies based on QIS, larger-scale efforts are needed to make these a reality.

To advance QIST to the next level, a major push to create well-engineered quantum technology systems is needed. Such systems will be designed, constructed and operated by teams of scientists and engineers that will be more encompassing than existing teams now working in the smaller laboratories that lead the field in innovation.

A QIST workforce needs to be developed. While industry has the best engineering capability, their engineers do not generally have comfortable familiarity with quantum mechanics. While universities have the greatest capability for training people in advanced theoretical and experimental knowledge, they do not have the ability to create and service products that can be used by industry or the general public. Thus, universities need to create education tracks to advance both theoretical skills and hands-on laboratory skills, and industry needs to incentivize this workforce by embracing quantum-prepared scientists and engineers and by training their own.

Industry and governments need to work together to create industry standards for product development and specification. In the US, such a partnership was recently announced. The Quantum Economic Development Consortium (QEDC) will be overseen by the US National Institute of Standards and Technology (NIST), and will work with industrial interests in QIST to create a stable marketplace for companies to sell quantum-related technologies, and eventually develop standards for commercial products.

Finally, continued governmental funding is needed for basic research, to continue developing innovative approaches for harnessing the radically new potentials of quantum phenomena for technology, both for industry applications and for basic science.

6. How did the NQI legislation in the US come about?

A decade ago in 2009, the US National Science and Technology Council (NSTC) issued a report, ‘A Federal Vision for Quantum Information Science.’ The report followed a workshop that brought together quantum scientists, computer scientists, mathematicians, and engineers, who surveyed the possible applications of QIST, and the possible paths to making these a reality. The report recommended, ‘The United States ... create a scientific foundation for controlling, manipulating, and exploiting the behavior of quantum matter, and for

identifying the physical, mathematical, and computational capabilities and limitations of quantum information processing systems in order to build a knowledge base for this 21st century technology' [1].

Since then, many other workshops with similar goals took place, sponsored by various universities and agencies (NSF, DOE, NIST, DOD...). The topics spanned a wide range of interests in advancing QIST, from chemistry to sensors to information technology to high-energy and nuclear physics. For example, a DOE-sponsored workshop in 2016 released a report titled, 'Quantum Sensors at the Intersections of Fundamental Science, Quantum Information Science, and Computing.' It pointed to 'the need to support cross-disciplinary teams addressing problems outside of any discipline; the need for long-term awards (5+ years) and multi-PI team awards to address grand challenges; the need for funding coordinated efforts at universities, government labs, and industry to allow effective translation of quantum technologies into practical application; and the great benefit provided by modest-sized seed grants to allow pursuit of high-risk/high-reward ideas' [2].

In June 2016, near the end of the final year of the Obama administration, the NSTC produced another report, 'Advancing Quantum Information Science: National Challenges and Opportunities.' This report was followed in October 2016 by a meeting organized by the White House Office of Science and Technology Policy, the 'OSTP Forum on Quantum Information Science,' again bringing together leading experts and proponents of developing QIST. In the same month, a group organized by the National Photonics Initiative (NPI)—a collaborative alliance among industry, academia, and government [3]—began an effort to educate members of Congress and their staffs about the benefits of developing a national strategy, which they named the *National Quantum Initiative*. Advised by the professional staff of The Optical Society (OSA) and the International Society for Optics and Photonics (SPIE), the authors of the present paper along with the NPI assembled a team of academics and industry scientists from across the US to write proposals which were submitted to members of Congress for consideration.

In June 2017 the NPI team discussed its proposal, 'Call for a National Quantum Initiative' with congressional staff of the US House of Representatives Committee on Science, Space and Technology. This was followed on 24 October by a formal hearing of that committee, titled, *US House Hearing on American Leadership in Quantum Technology*, with testimony by academics (including one of the present authors, CM), industry, and government agency leaders from NIST, NSF and DOE. In April 2018 the NPI team submitted a second proposal, titled 'National Quantum Initiative Action Plan' to the same House committee, and in June 2018 that committee introduced a bipartisan bill (H.R. 6227) to authorize the creation of the 'National Quantum Initiative' and defining NSF, DOE, NIST, and the White House's roles in it. In the US system, authorization bills such as this one do not appropriate specific funding levels; rather they authorize Congress and the Administration to move a program forward. On 13 September 2018 the full House of Representatives voted and passed H.R. 6227 to authorize the 'National Quantum Initiative Act.'

In parallel, in June 2018, the Senate Committee on Commerce, Science, and Transportation released their bipartisan version of the House bill, S.3143, to create a 'National Quantum Initiative.' The final piece of the puzzle was placed when the Senate Committee on Energy and Natural Resources introduced a bill that included Senate authorization for DOE involvement in the NQI. Following that, the House and Senate negotiated to resolve differences between the bills into a single bill that was passed out of Congress and sent to the President. Toward this goal, that Senate committee held a formal hearing on 25 September 2018, at which further testimony was heard from leaders in industry, government, and academia. The bill was signed into law 21 December 2018.

Key Events in Development of the US NQI

Date	Document/event	Source
June 2016	Advancing Quantum Information Science: National Challenges and Opportunities	White House Office of Science and Technology Policy [4]
June 2017	Call for a National Quantum Initiative	National Photonics Initiative (M Raymer, C Monroe <i>et al</i>) [5]
24 October 2017	US House Hearing on American Leadership in Quantum Technology	US House of Representatives Committee on Science, Space and Technology [6]
April 2018	National Quantum Initiative Action Plan	National Photonics Initiative [7]
June 2018	US House Resolution H.R. 6227, National Quantum Initiative Act, introduced	US House of Representatives Committee on Science, Space and Technology [8]
13 September 2018	H.R. 6227 passed the US House of Representatives	Congress.gov [9]
June 2018	Senate bill S.3143, National Quantum Initiative Act, introduced	US Senate Committee on Commerce, Science, and Transportation [10]
September 2018	National Strategic Overview for Quantum Information Science	Subcommittee on Quantum Information Science, NSTC [11]
21 December 2018	H.R. 6227—National Quantum Initiative Act text	Congress.gov [12]

On 24 September 2018, the OSTP hosted the *White House Summit on Advancing American Leadership in Quantum Information Science*, to bring together many interested parties from academia, industry and government. The summit coincided with the Executive Branch's release of the report, 'National Strategic Overview for Quantum Information Science,' by the Subcommittee on Quantum Information Science under the Committee on Science of the National Science & Technology Council (NSTC). The report emphasizes goals to 'improve our capacity for cutting edge research and development, expand the QIS-literate workforce, and seamlessly coordinate between government, academic and private sector players.'

The speed of action and level of coordination between both legislative chambers, both political parties, and the White House, in promoting QIST is remarkable. This stems from not just the economic benefits of a quantum-fluent technology sector in the US, but also the fact that many leading powers throughout the world are focusing efforts in this area. Austria, Australia, Canada, and the United Kingdom have long featured outsized federal research budgets in QIST. Europe as a whole, and China too, have now recently chimed in with multi-billion dollar proposed investments in this area.

7. What does the National Quantum Initiative Act call for?

The merged House and Senate bill calls for a coordinated, coherent program of research, development, and setting of standards to advance QIST in the name of economic and national security. It calls for new, major centers to be created, which would focus on advancing quantum technologies using the highest levels of scientific and engineering know how working in concert. It also calls for sustained investment in exploratory research into the fundamentals of QIS, to seed the ongoing innovation of new QIST systems.

Under the National Science and Technology Council, the bill empowers the Subcommittee on Quantum Information Science of the NSTC to: coordinate the QIST research and education activities and programs of the federal agencies; recommend federal infrastructure needs to support the program; and evaluate opportunities for international cooperation with strategic allies.

The bill also calls for a National Quantum Coordination Office, with a director appointed by the Director of the Office of Science and Technology Policy, in consultation with the Secretary of Commerce, the Director of the National Science Foundation, and the Secretary of Energy. The Coordination Office should, for example, provide technical and administrative support to the NSTC Subcommittee; oversee interagency coordination of the Program; ensure coordination between the various Centers for QIST research; and promote access, through appropriate government agencies, to existing quantum computing and communication systems developed by industry, academia, and federal laboratories to the general user community in pursuit of discovery of the new applications of such systems.

Furthermore, the bill instigates a needed effort in the training of a generation of scientists and engineers knowledgeable in QIST to power the economic and scientific revolution that will be enabled by the new developments.

8. Summary and conclusions

In summary, a consensus has formed in the scientific and industrial communities in the US that a new, revolutionary generation of technologies is possible, although still in its infancy. Not yet ready for full-scale commercial development, these technologies will, if successful, reach into almost every sector of the US economy. To reach this potential, governmental investment is needed, while preserving an open, 'science-first' approach to stimulate and enable new discoveries that ultimately will lead to a new era, not unlike the semiconductor industry revolutionized communication and computing in the past several decades.

Acknowledgments

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References

- [1] A Federal Vision for Quantum Information Science <http://calyptus.caltech.edu/qis2009/documents/FederalVisionQIS.pdf>
- [2] Chattopadhyay S, Falcone R and Walsworth R 2016 Quantum sensors at the intersections of fundamental science, quantum information science & computing *Report of the DOE Roundtable* US Department of Energy Office of Science https://science.energy.gov/~media/hep/pdf/Reports/DOE_Quantum_Sensors_Report.pdf

- [3] The National Photonics Initiative (NPI) is a collaborative alliance among industry, academia and government. The NPI is led by The Optical Society (OSA), and SPIE, the International Society for Optics and Photonics (SPIE), with support from other scientific societies including the American Physical Society (APS), the IEEE Photonics Society, and the Laser Institute of America (LIA) <https://lightourfuture.org/home/>
- [4] https://whitehouse.gov/sites/whitehouse.gov/files/images/Quantum_Info_Sci_Report_2016_07_22%20final.pdf
- [5] <https://www.lightourfuture.org/home/about-npi/resources/>
- [6] <https://science.house.gov/legislation/hearings/american-leadership-quantum-technology>
- [7] <https://lightourfuture.org/getattachment/85484dca-465a-46f4-8c8c-090aeb845d09/FINAL-Action-Plan-for-a-NQI-Apr-3-2018.pdf>
- [8] <https://congress.gov/bill/115th-congress/house-bill/6227>
- [9] <https://congress.gov/bill/115th-congress/house-bill/6227/all-info>
- [10] <https://congress.gov/bill/115th-congress/senate-bill/3143?q=%7B%22search%22%3A%5B%22S.3143%22%5D%7D&r=1>
- [11] <https://whitehouse.gov/wp-content/uploads/2018/09/National-Strategic-Overview-for-Quantum-Information-Science.pdf>
- [12] <https://congress.gov/bill/115th-congress/house-bill/6227/text>