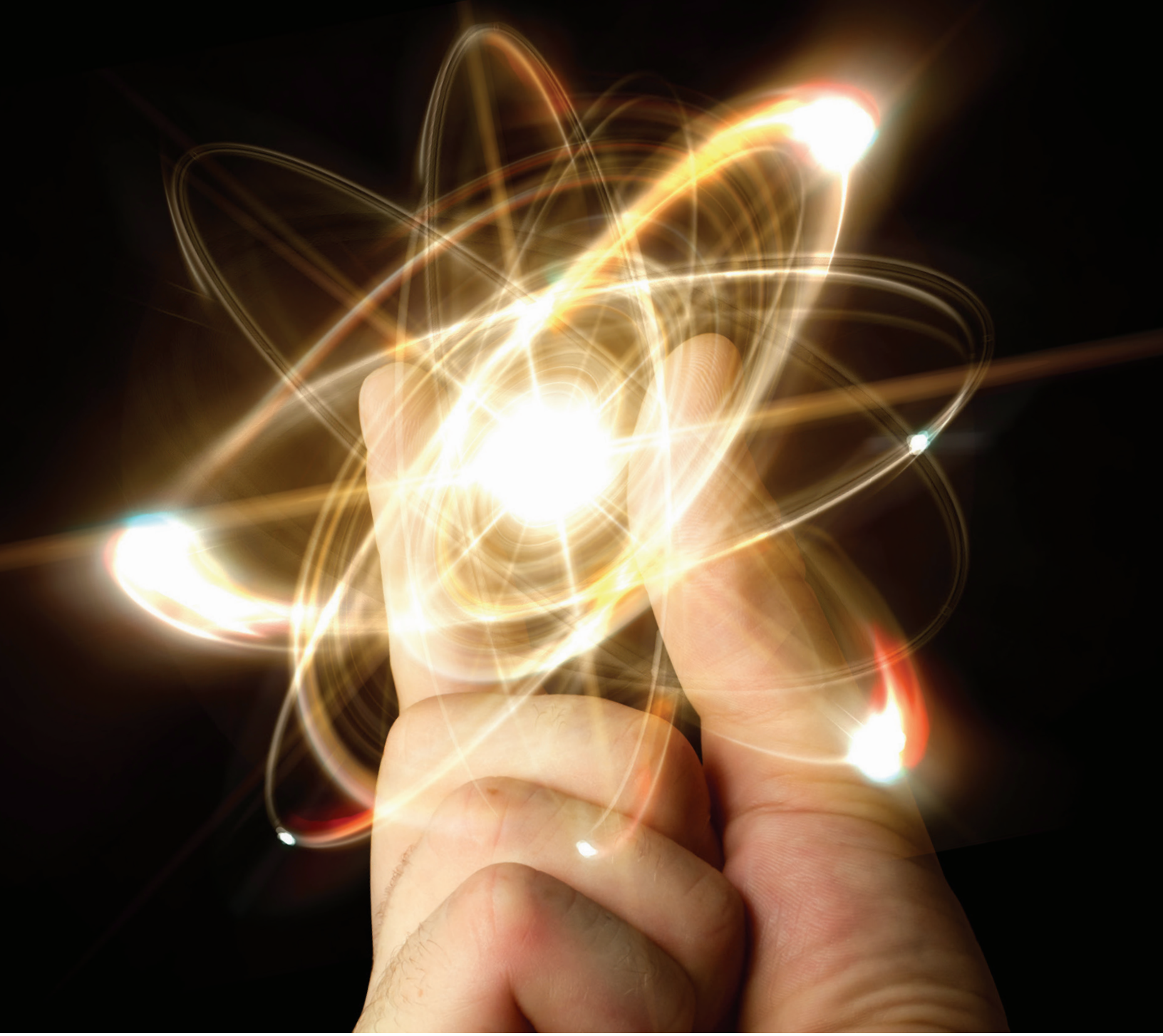

Seizing Canada's Quantum Opportunity

Report on the Quantum Canada Symposium and Workshop

April 11–12, 2017

Canada NRC·CNRC

NSERC CRSNG

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Catalogue no. NR16-151/2017E
ISBN 978-0-660-08954-6

Purpose

The purpose of this report is to document participant discussions and to highlight insights from the Quantum Canada Symposium and Workshop on April 11–12, 2017. The information presented here and the subsequent feedback process will continue the dialogue among the quantum community towards the ultimate goal of developing a robust national quantum strategy for Canada.

The two-day event in Ottawa was hosted by the National Research Council of Canada (NRC), the Natural Sciences and Engineering Research Council of Canada (NSERC), and the Canadian Institute for Advanced Research (CIFAR). It brought together scientists, industry players and government representatives to explore how Canada can build on its strengths in quantum science and chart a path towards global leadership in future quantum technologies.

The event was designed to build on the findings of the Quantum Canada national survey, launched in September 2016 and compiling data from more than 350 respondents in Canada's quantum community. Community members identified several priorities in terms of ensuring Canada's future success in quantum, including: support for recruitment and training of highly qualified personnel for a range of R&D activities; the need for a clear national vision for Canada's interests in quantum; and enhanced collaboration among academic institutions, government organizations and industry.

The discussions were open and wide-ranging, providing participants with the opportunity to put a variety of ideas on the table. The goal was to foster an exchange of ideas, identify issues of importance to the quantum community, and allow participants to discuss potential approaches to help Canada maintain and expand its present-day advantage in the emerging quantum sector.

More than 200 individuals from universities, government organizations and private industry attended the first day's proceedings – a symposium that included presentations by scientific, technology, industry and government leaders. On the second day, discussions continued at a workshop with 60 participants. This diverse group included Canadian scientists leading their fields in quantum research, companies engaged in or pursuing quantum technologies, and policy-makers with an interest in the potential of quantum applications to address important Canadians problems and national priorities.

Quantum Canada Vision

A vibrant Canadian quantum ecosystem with world-leading R&D, innovative technologies, and globally reaching Canadian companies – all driving social, economic and environmental solutions for Canada

Keynote speakers from the Quantum Canada symposium

Front row (left to right): Dr. Mario Pinto, Dr. John Hepburn, The Honorable Zachary J. Lemnios, Mr. Iain Stewart, Dr. Ben Sussman

Back row (left to right): Dr. Duncan Stewart, Sir Peter Knight, Dr. Paul Corkum

Missing: Mr. Scott Jones

Call to Action

Members of the quantum community recognize that Canada has a significant opportunity to continue as a global leader in quantum but success is not guaranteed. The path from today's quantum science excellence to tomorrow's innovative impacts for Canada will ultimately require a cohesive national vision, supporting infrastructure and a blueprint for action.

At the event, a "call to action" was issued to the quantum community: Let us collaborate to determine the strategies and activities that will propel Canada towards future success in the quantum sector, by answering three core questions:

1. How can we work together as a community to solve big Canadian problems?
2. What must we do to maintain and grow science excellence in quantum?
3. What must we do to convert that science excellence into technology impact for Canada?

"We need to build on our quantum science strengths to develop technologies that will benefit Canadians in areas such as health, communications, environment, resource management and more. We must look at how quantum can help us address our societal challenges; how do we make quantum a key component of solving Canadian problems not just today but for the future?"

– Mr. Iain Stewart, President, NRC

Canada's Quantum Opportunity

A foundation of science excellence

The Quantum Canada symposium featured a keynote presentation from Sir Peter Knight, a globally recognized quantum scientist who played an influential role in developing quantum as a science and technology priority for the United Kingdom (UK). Sir Peter described Canada as a strong and highly respected player in the global quantum research and development (R&D) landscape. He cited McKinsey data published in The Economist in March 2017[1], which ranked Canada fifth in the world in annual spending on quantum research.

"It is critical to connect the best Canadian scientists with the best scientists around the world to generate transformative new knowledge. Through our quantum information science and quantum materials efforts, eminent Canadian researchers have been working with international colleagues to push the frontiers of quantum science. This collaborative international research has supported Canada's development as one of the world's leading quantum nations and these valuable partnerships are needed to ensure our ongoing leadership."

– Dr. John Hepburn, Vice-president, Research, CIFAR

Over the past decade, Canada has invested more than $1 billion in quantum R&D. The Natural Sciences and Engineering Research Council of Canada (NSERC) supports a number of research initiatives and centres of excellence in quantum. The Canadian Institute for Advanced Research (CIFAR) supports two international, interdisciplinary research networks related to quantum: quantum information science and quantum materials. The National Research Council's Quantum Photonic Sensing and Security program is collaborating with industry, government and universities to develop the quantum photonics technology platform, and to develop and deliver applications in quantum cyber security and photonic sensing.

Additionally, the Canadian Foundation for Innovation (CFI) has invested at least $100 million in research infrastructure in quantum, and three Canada First Research Excellence Fund (CFREF) awards, valued at more than $200-million, have been granted to support quantum research facilities and programs.

Innovation capacity

The quantum community sees the potential for quantum applications to transform existing industries and foster development of new industries. Creating both types of technological growth is consistent with one of the Government of Canada's key objectives for its Innovation Agenda: "Identify ways for Canada to harness emerging

[1] "Technology Quarterly, Here, there and everywhere: Quantum technology is beginning to come into its own," The Economist, March 9, 2017. http://www.economist.com/technology-quarterly/2017-03-09/quantum-devices

technologies that would create jobs and industries that never existed before, while reinvigorating established industries." [2]

"Canada has some of the finest quantum research centres in the world. Strengthening the links among these centres can better prepare us for the quantum revolution. By setting aside boundaries and sharing resources, our science excellence in quantum can grow even stronger. The Networks of Centres of Excellence program provides such an option."

– Dr. Mario Pinto, President, NSERC

Canada has a strong base of industries that stand to benefit from quantum technology advances, and whose capacities in design, manufacturing and distribution could support development of quantum systems and devices. Such industries include Canada's photonics sector, in which approximately 400 photonics companies employ more than 25,000 people and collectively generate close to $4.6 billion in revenue each year. [3]

In addition to offering a boost to current industries, quantum technologies are already laying the foundations for new industries. A number of Canadian companies are pushing the boundaries, including D-Wave Systems in Vancouver, British Columbia; Anyon Systems in Dorval, Quebec; and multiple start-up firms in such areas as quantum computing software and natural resources sensing.

"Canada's quantum research funding and science expertise have made it one of the world's leading quantum nations."

– Sir Peter Knight, Imperial College London

The Imperative for Action

As many countries increase investment in quantum R&D, and consider or execute national quantum strategies, the urgency increases for Canada to seize its own quantum opportunity.

Quantum R&D is moving into a new era where the science is yielding technology applications with commercial potential. This transition, which is often called the "second quantum revolution" or "quantum 2.0", is driving other science-leading quantum nations to boost investments, and develop strategies and action plans to drive quantum innovations. These regions and countries include the U.S., UK, European Union, Australia and China.

Many global technology companies are also staking claims on the future promise of quantum, including IBM, which is a leader in quantum computing R&D. IBM's Vice President, Physical Sciences & Government Programs, Zachary J. Lemnios, a keynote speaker at the Quantum Canada symposium, urged Canada to keep pace with other nations and develop concrete strategies for driving innovation from research advances.

"Canada has a real opportunity here – the kind of opportunity that arises maybe once or twice in our careers. And Canada needs to move now – the window for taking advantage of the opportunity is within the next one or two years. The time has come for all of us to think larger, as engineers, scientists and policy experts and ask: How do we grow an industry, an engineering enterprise that takes research and translates it into an industry that people can use?"

– The Honorable Zachary J. Lemnios, Vice President, Physical Sciences & Government Programs, IBM

Quantum Moonshots

Quantum technologies have potential to help solve large-scale problems of importance to Canada in natural resources, health, environment, defence, national security and more.

"Set big-horizon goals and create broad-based partnerships to fund ambitious research projects that solve complex, large-scale problems and spark commercial opportunities for the private sector."

– Hon. Navdeep Bains, Minister of Innovation, Science and Economic Development [4]

Amongst a number of potential quantum moonshot opportunities, the Quantum Canada event highlighted two areas for discussion: cyber security and national defence. Government agencies in these areas are striving to be early adopters of quantum technologies, with research that could be translated to private-sector, commercial applications.

Protecting critical cyber systems and information

Canada's Communications Security Establishment (CSE) is responsible for protecting Canada's systems of importance. According to Scott Jones, the Assistant Deputy Minister responsible for the Information Technology Security program at CSE, the emergence of quantum computing poses a serious threat to Canada's information and communication technology systems.

> **"Canada has an opportunity to succeed in next-generation quantum computing and cryptography. We have a choice – is quantum going to be a threat for encryption or can it be an opportunity? We all need to collaborate to ensure a quantum-ready future for Canada."**
>
> – Mr. Scott Jones, Assistant Deputy Minister of the Information Technology Security program, CSE

Mr. Jones told the Quantum Canada symposium participants that quantum computing is expected to make today's encryption methods ineffective, which is why CSE has been tasked with finding a solution to protect classified and personal information that has been entrusted to the Government. However, Mr. Jones stressed that this isn't something that CSE can do alone. He discussed the necessity for industry, academia and government to collaborate to find a solution, and emphasized the importance of preparing the next-generation of scientists, mathematicians and engineers to ensure they have the appropriate skills to address the quantum challenge.

Strengthening Canada's defence capabilities

Another federal organization conducting research into quantum technologies is Defence Research and Development Canada (DRDC), which provides integrated science and technology (S&T) advice and technical solutions to the Department of National Defence, the Canadian Armed Forces, and the public safety and national security communities.

With the emergence of new and powerful sets of quantum technologies in sensing, computing and materials development, DRDC is investigating how quantum advances could provide Canada with superior defence capabilities in areas such as communications, surveillance, navigation and operational effectiveness.

Global initiatives are also driving Canadian defence-related quantum research. Canada's partners in the Five Eyes intelligence-sharing alliance (U.S., UK, Australia and New Zealand) are also exploring quantum applications. While each nation requires sovereign defence capabilities, the alliance benefits with the transfer of new technologies and capabilities.

Maintaining and Growing Science Excellence in Canada

One of the three core questions the quantum community is addressing is: "What must we do to maintain and grow science excellence in quantum?"

Canada's quantum community recognizes the importance of continuing to invest in basic, or undirected, quantum research. It will be important for Canada to remain "ahead of the curve" in basic research as quantum knowledge continues to evolve around the globe.

At the same time, Canadian quantum scientists recognize the need and benefit of expanding applied, or directed, research, to help shape innovation.

Participants at the Quantum Canada workshop explored what Canada can do to maintain and expand its quantum science excellence through discussions on three components seen as critical to ongoing research leadership:

1. Facilities
2. Highly qualified personnel (HQP)
3. Collaboration

Key insights from these discussions are captured in the following sections.

[2] *Innovation for a Better Canada: What We Heard*, Innovation, Science and Economic Development Canada, 2016.

[3] *Light Technologies: A Strategic Economic Asset*, Executive Summary, Canadian Photonic Industry Consortium, 2016.

[4] "Minister Bains delivers keynote address on Canada's Innovation Agenda," media release, Innovation, Science and Economic Development Canada, October 19, 2016.

"It is generally agreed that innovation is a main driver of sustained economic growth. Innovation leads to new markets, new possibilities, new technologies and new health practices and drug therapies. But innovation does not occur in a vacuum. It emerges from a base of knowledge and ideas – a ground-level understanding of how things work. And this comes from science and the people who do it."

– Hon. Minister Duncan, Minister of Science[5]

Facilities

Existing strengths and successful models discussed

High-quality research facilities underpin scientific excellence and Canada has a strong foundation in this area. Through decades of investment, Canada has developed world-leading research facilities in various areas of quantum specialization, in all major regions of the country.

Workshop participantsdiscussed successful facilities models, and related HQP and collaboration programs, including:

- Canada First Excellence Research Found (CFREF)
- Canada Foundation for Innovation (CFI)
- Quantum Works
- Genome Canada
- Atomic Energy of Canada Ltd.
- Infrastructure-intensive research (SNOLAB, Astrophysics)
- Compute Canada
- Industrial partnership model used by the Institute for Quantum Computing (IQC)
- CANARIE and ORION

Discussed areas of focus for improvement

Participants also discussed current challenges in building and sustaining research facilities, and areas where improvements might be made. Potential areas of focus included:

- A comprehensive inventory of research infrastructure (facilities and equipment) to assess strengths, as well as gaps, to allow development of a strategic plan to optimize facilities' use and resource-sharing, and plan for potential new facilities
- Research centres' ability to access funding for ongoing operational costs and for facilities upgrades over time.
- Canadian industry's financial capacity to invest or co-invest in research infrastructure with universities and governments
- Ability of government laboratories to provide access to small and medium-sized enterprises (SMEs) to conduct research and test prototypes

Potential activities discussed to support facilities enhancements

Workshop participants discussed a number of options to strengthen Canada's quantum research facilities and their operations, including:

- Explore ways for industry players (particularly start-ups) to gain expanded access to enabling government labs for minimal or no cost
- Examine innovative "user-based models" (similar to the U.S. Department of Energy) for new facilities to encourage collaboration and scientific excellence
- Consider developing new facilities to add important capacity for technology development. Potential examples include:
  - A fabrication facility to develop quantum-related materials and components for research
  - A low temperature facility for electronic devices for superconducting qubits
  - Access to a fibre network that is "representative" of a real network for research into quantum communications technologies; access to "dark fibre" as a test bed for collaborative research
  - Interfacing quantum networks, satellite-based communication, sensing, and computing infrastructure
  - National facility demonstration platforms, for example a national quantum key distribution (QKD) network or quantum internet
  - A metrology infrastructure to underpin the technology being developed and implemented
- Look at ways to increase facilities-sharing via Networks of Centres of Excellence (NCEs), and by having industry researchers co-locate with researchers in university and federal labs

[5] Remarks by the Hon. Kirsty Duncan, Minister of Science, to the Mississauga Board of Trade, May 5, 2017.

Highly qualified personnel (HQP)

Strengths discussed

Canada's quantum community recognizes that recruiting and training highly qualified personnel (HPQ) is an essential priority for ongoing research excellence. Workshop participants discussed a number of Canadian strengths in this category, including:

- Strong funding and other support mechanisms dedicated to research activities and talent-building for HQP, including Discovery Grants for early-career researchers
- The high quality of Canadian academic education in quantum science, including:
  - Student access to excellent research facilities
  - Internationally known summer programs in quantum science
- A number of strong scholarship programs, including post-graduate scholarships from funding agencies and universities
- Research facility partnerships with international institutes, which expand learning and research opportunities for students

Discussed areas of focus for improvement

Participants also discussed the forces acting against Canada's attraction and development of HQP in quantum research, including competition from other nations. They identified potential areas where improvements could be made, including:

- Educational programs to train quantum engineers to develop expertise in the transfer from quantum science to technology
- Opportunities to allow Canadian quantum science students to gain experience in relevant industries and access to entrepreneurial training
- Immigration policies and tuition fees that affect Canada's ability to attract foreign students, in the face of increasing global competition for those students
- The capacity of industry to articulate long-range personnel requirements, to help universities and governments establish training priorities and make strategic funding investments
- Canada's ability to attract young people to study in STEM fields

Potential activities discussed to enhance recruitment and training of HQP

Workshop participants then discussed potential activities to strengthen HQP recruitment, development and mobility in Canada and internationally. Ideas included:

- Consider new mechanisms to give students more exposure to other research facilities and programs in different parts of Canada, and to facilitate their access to national laboratory facilities
- Examine possible fast-track immigration processes to attract quantum students and researchers from other nations, as well as scholarships and fellowships for international students and post-docs
- Explore additional international networks to enable more exchanges of students across borders
- Assess the feasibility of educational programs that combine science and engineering, e.g., joint physics and engineering degrees in quantum
- Look at STEM recruitment strategies for elementary- and secondary-school levels, including specific strategies to attract females to these fields
- Consider potential "mass-appeal" communications channels to broaden interest in quantum science (e.g., quantum YouTube channel)
- Examine options for training students in entrepreneurship in quantum technologies, to support development of next-generation quantum companies
- Examine feasibility of new partnerships with industry to create quantum-related career paths for students

Collaboration

Collaboration among researchers – within nations and internationally – is considered foundational to research excellence. Canada's quantum community believes its cooperative and collaborative approaches and processes have contributed to its leadership among quantum nations, while also recognizing that more could be done.

Strengths and successful models discussed

Workshop participants discussed a number of models for successful collaboration, including:

- Quantum Works boosted collaboration through such mechanisms as student exchanges and frequent workshops
- Various international collaborations have been successful, such as Genome Canada co-funding international projects with other nations, and collaboration between other nations' research institutes and Canadian academic research centres
- Some research networks offer funding incentives to encourage collaborations

Discussed areas of focus for improvement

Recognizing that barriers do exist against collaboration within Canada and internationally, participants considered a number of areas where improvements may be needed, including:

- Increased tools to promote and provide incentives for collaboration
- More flexible agreement frameworks to support partnerships between government and university laboratories, e.g., by expanding current frameworks that support university-industry partnerships to also include government
- Potential new mechanisms for supporting large collaborations aimed at ambitious national science and technology goals ("moonshots")
- Expanded opportunities for Canadians to bring in international collaborators to deal with Canadian research priorities

Potential activities discussed to enhance collaboration

Participants put forward ideas on how to build on Canada's strong record of collaboration, including:

- Explore ways to create targeted research opportunities that draw in diverse players, e.g., by focusing R&D around a "grand challenge" – where the quantum research community can bring together the most appropriate researchers/expertise/infrastructure assets to solve a specific problem. This is along the lines of the model used by the Defense Advanced Research Projects Agency (DARPA) in the U.S.
- Consider support for a collaborative network that has a flexible mechanism for industry buy-in
- Look at creation of a consortium or a pre-competitive collaborative research network, similar to that of the UK
- Examine options for hosting meetings among researchers and between researchers and industry, in different regions of the country, to energize cross-Canada collaboration
- Look at increasing the dialogue between the research community and different industry sectors – to help scientists learn more about industry problems and priorities, and help industry better understand how quantum R&D could provide solutions
- Analyze and consider successful collaborative models from other countries, including:
  - The National Institutes of Standards and Technology (NIST) in the U.S., which has close collaborations with the Joint Quantum Institute (JQI) at the University of Maryland, and operates JILA – a joint institute between Colorado University Boulder and NIST
  - The Centres of Excellence in Australia, where centres are given long-term funding specifically for collaboration
  - The "hub and spokes" model used in the UK
- Consider identification of champions to coordinate stakeholders and lead the national effort to support and advance Canadian quantum efforts

Driving Innovation

> **"A big change is occurring. Governments are recognizing the massive opportunities in emerging quantum technologies and taking action to capitalize on those opportunities. Canada cannot afford to stand still. It also needs to take action to convert its fundamental science strength in quantum into technology leadership – or risk being left behind."**
>
> – Sir Peter Knight, Imperial College London

Participants in the Quantum Canada workshop explored ways in which Canada can develop the quantum technology devices and systems that will yield the greatest innovation benefits to Canada.

Canadian science strengths with potential for transformative technology

Workshop participants examined areas where Canadian science expertise is strong and provides a foundation for applications with market potential, in other words, areas in which Canada is in a strong position to achieve technology and economic "wins."

In the 2016 Quantum Canada survey, respondents were asked to identify the top 3 application areas in Canadian quantum R&D, and they named quantum sensing, imaging and metrology; quantum secure communications and networks; and quantum computing and algorithms.

Quantum solutions of particular relevance to Canada

Participants held discussions on another important component of technology development: the quantum applications that can be used to address the requirements of particular interest to Canada.

Defining these "Canada-specific problems" that could be addressed by quantum technologies included examination of the following:

- Quantum solutions to address problems/challenges or enhance performance in key Canadian industries (e.g., oil and gas, telecommunications)
- Solutions to support national priorities (e.g., environmental/clean tech, digital transformation, security and defence)
- Solutions that more broadly support economic goals such as trade, productivity and economic growth, driven by a highly trained workforce

Workshop participants then explored options for strategic approaches and activities to provide Canada with the best opportunities to lead in quantum innovation.

Key insights from their discussions are presented in the following section.

High-impact Canadian opportunities in quantum technologies

Workshop participants looked at various factors that could help Canada's quantum community identify opportunities for Canadian technology innovation, including research expertise in quantum, industrial capacity, and sectors that could benefit from quantum technology to solve specific challenges, among other factors.

1. Areas of research expertise with potential for marketable technologies:

- Engineering quantum devices
- Novel quantum materials
- Quantum photonics
- Quantum computing in superconducting or solid-state qubits
- Quantum communications theory and demonstration
- Secure cloud-based computing
- Quantum-safe cryptography
- Quantum modelling and simulation for first-generation quantum computers

2. Strong industrial capacity:

- Foundation of manufacturing capacity in photonics and medical devices
- D-Wave Systems: Canadian company is world's first commercial quantum annealing machine
- Quantum software start-ups in quantum-safe cryptography and quantum computing

3. Relevant Canadian sectors and potential quantum applications:

- Natural resources sector: sensing in energy and mining
- Environmental and climate challenges: sensing and monitoring environmental elements, computation for efficient synthetic nitrogenase reaction
- Critical infrastructure: monitoring critical infrastructure in energy and transportation sectors
- Telecommunications: secure satellite-based and fibre-based quantum communication networks (quantum internet)
- Financial services: modelling, security, and precision timing
- Defence: big data analysis, secure communication, stealth detection, and navigation
- Agriculture: improved weather forecasting, manufacturing fertilizers
- Health: enhanced sensing and imaging, and simulation for new drugs

4. Areas where classical/fundamental physical limits have been or will soon be reached:

- Gravitational sensors
- Classical optical telecommunication networks
- Positioning, navigation and timing
- Stealth detection
- Environmental/remote sensing and monitoring
- Small-scale sensing and imaging

5. Synergies between Canadian R&D strengths:

- Intersection of photonics and materials
- Photonics and telecommunications
- Photonics and quantum sensing
- Intersection of quantum computing and artificial intelligence

Potential strategies and activities discussed to accelerate quantum technology development

Participants wrapped up their discussion of quantum technologies and innovation, by proposing strategies and action steps that could accelerate the quantum science-to-technology conversion. These ideas included:

- Look at building a consortium of key stakeholders. Many suggested following the foundational model of "Genome Canada" or SEMATECH
- Explore development of a government/industry partnership tasked with creating a quantum roadmap specific to Canada, similar to what the semiconductor sector did in the 1970s to help build the industry
- Explore ways to effectively communicate to key stakeholders on the urgency of stepping forward to protect Canada's quantum interests; the threats that could emerge (e.g., to current encryption methods); and the added value that quantum solutions could provide
- Analyze options for developing criteria for assessing top-priority focus areas, e.g., compare alternative processes by which the quantum community and stakeholders can decide which key projects/areas of investment should be focused on
- Consider setting up diverse forums to promote broader understanding of potential impacts of quantum. Potential themes and approaches for such forums include:
  - User-specific and sector-specific forums, where scientists can learn more about industry problem areas and explore where quantum technologies might create impact
  - Focus on increasing awareness and understanding of the potential of quantum technologies within current technology platforms (communication, computing and sensing organizations) and Canadian industrial sectors (health, environment, energy, mining, agriculture, finance, etc.)
  - Connections with industry associations and specific companies to examine potential opportunities for engagement
  - Possible model for setting up dialogue is Réseau photonique du Québec – a network of photonics companies
- Consider encouraging government to take on the role of early buyers and prototype testers. This would support an early move to prototyping and demonstration projects, as was done in the UK, for example. Once prototypes are developed, it is easier to attract private sector investors
- Explore ways to support a start-up culture:
  - NSERC's CREATE granting program is a possible vehicle to support students to create a start-up culture
  - Setting up incubators at research centres is one option
  - Prioritize existing industries that enable a start-up culture (e.g., quantum computing)
- Look at options to support rapid knowledge transfer that feeds back into Canada. For example, allow students to become interns in leading companies in quantum outside Canada through internship opportunities, with incentives to return to Canada
- Explore grand-challenge problem platforms: similar to the U.S. DARPA model in which defence researchers define a problem and build a team, which includes industry experts, for a specified period of time to solve the problem
- Consider developing the standardization, equipment calibration, and metrology required to support technology implementation
- Look at framing quantum technologies as an enabling technology platform that feeds other technologies
- Analyze options for encouraging patent filing as appropriate within granting programs

"Quantum is perhaps the greatest disruptive innovation for which Canada has an opportunity to lead globally. We have first-class research and engaged stakeholders in industry and government. Seizing this opportunity will help us improve Canadians' lives."

– Dr. Ben Sussman, Program leader, Quantum Photonic Sensing and Security, NRC

Further issues to discuss

Workshop participants agreed the following topics, among others, would be valuable to explore in future sessions:

- Governance models for the quantum community

- Mechanisms for integrating federal and provincial priorities in R&D planning
- Approaches to help ensure Canada can retain its quantum talent, rather than lose it to other nations

Moving Forward

The Quantum Canada workshop concluded with a discussion of key next steps.

1. Participants agreed to hold workshops to bring together quantum researchers and key players in specific industry sectors, to explore potential applications of value to these sectors. The following key stakeholders were discussed for engagement:
   - Equipment manufacturers
   - Defence contractors
   - Health
   - Energy and natural resources; mining
   - Telecom service providers; telecom device manufacturers
   - Finance, financial tech providers and banks
   - Advanced manufacturers, laser machining companies; other photonics-related manufacturers
   - Venture capitalists
   - Experts in machine learning - intersection between machine learning and quantum
   - Provincial governments
2. A commitment was made to build on the insights generated from this event, conduct additional consultations, and work to develop the first iteration of a national quantum strategy for Canada by the fall of 2017.

Participants agreed to intensify the quantum community's collaboration and communication to achieve their members' shared goal – to maintain Canada's global leadership in quantum science, and to position this country for global leadership in quantum technologies and industries.

The quantum community believes Canada has an opportunity to harness its quantum science excellence to drive innovations that will benefit the economy, the environment and the social fabric of the country, for decades to come. And it believes the opportunity must be seized now, as other leading quantum nations move ahead to build their competitive edge in this transformative area of technology.

Appendix A: Glossary of terms

CFI	Canadian Foundation for Innovation
CFREF	Canada First Research Excellence Fund
CIFAR	Canadian Institute for Advanced Research
CSE	Communications Security Establishment
DARPA	Defense Advanced Research Projects Agency
DRDC	Defence Research and Development Canada
HQP	Highly qualified personnel
IQC	Institute for Quantum Computing
JQI	Joint Quantum Institute
NCE	Networks of Centres of Excellence
NIST	National Institutes of Standards and Technology
NRC	National Research Council of Canada
NSERC	Natural Sciences and Engineering Research Council of Canada
QKD	Quantum key distribution
R&D	Research and development
SMEs	Small and medium-sized enterprises
S&T	Science and technology
STEM	Science, technology, engineering and mathematics
UK	United Kingdom
U.S.	United States

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