IOP Institute of Physics

Submission to the Commons Science and Technology Committee on the opportunities and challenges for quantum technologies

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The Institute of Physics welcomes the opportunity to contribute to the Science and Technology Committee's quantum technologies inquiry.

Summary

- As the initial phase of the UK National Quantum Technologies (UKNQT) programme comes to an end in 2019, further investment will be required to secure and strengthen the UK's position. Commitments to a new round of investment should be made as soon as possible, as any perceived drop off in the level of financial support could lead to the loss of expertise currently in the UK and deter potential talent and investors, both within the UK and from overseas.
- There are several outstanding recommendations of the Government Office for Science's (GO-Science) report, including those relating to the establishment of innovation centres to promote technology commercialisation, and the creation of an overarching coordinating body, that should form part of the next tranche of funding.
- The coordination and unified structure provided by UK Research and Innovation (UKRI) should enable funding to be allocated more strategically, to better capitalise on areas of UK strength and derive the greatest possible benefit.
- To fully realise the economic and societal benefits of quantum technologies, the UK needs to convert its strong research base into commercial products, by deepening connections between academia and industry, and capitalising on relevant industrial strengths. A clear plan to increase the level of meaningful industrial engagement should be central to any future quantum technologies programme.
- It is essential that fundamental quantum physics research underpinning the development of quantum technologies that is funded outside of the UKNQT programme is supported.
- Any future programme should include a review of the landscape to identify any emerging areas that were not included within the scope of the original programme that may benefit from access to programmatic support and strategic alignment.
- Successful development of quantum technologies in the UK will require continued access to overseas talent, funding, markets and regulatory influence post Brexit. Clarity is urgently needed regarding arrangements following the UK's exit from the European Union, if the quantum technologies community is to avoid losing talent and access to international research programmes.
- The development of quantum technologies requires a highly skilled and multidisciplinary workforce, with expertise in fields including engineering, manufacturing and business, as well as physics. The growing STEM skills shortage

in the UK may present a barrier to the successful development and commercialisation of quantum technologies.

The progress that has been made on the recommendations in the Government Office for Science's 2016 report

1. Quantum technologies, based on the exploitation of quantum mechanical properties, have the potential to transform modern life, promising revolutionary new products and services in fields such as communications, infrastructure and healthcare. In addition, GO-Science and the UK quantum technology community estimate that this second 'quantum revolution' could bring significant benefits to the UK economy, potentially leading to the development of a sector comparable in size to the consumer electronics sector (worth £240 billion a year worldwide in 2016)[1] and creating thousands of high-value UK jobs.[2,3]

2. The UK has historically been at the forefront of quantum technologies research – as evidenced, for example, by its leading role in the development of one of the most established and transformative quantum technologies, the atomic clock – and today the UK research base enjoys a competitive global position. Research from Elsevier[4] ranked the UK's field-weighted citation impact (an indicator of research quality and impact) in quantum technologies as second only to Germany among 12 comparator countries[5] in 2014.

3. The five-year £270-million UKNQT programme was one of earliest and largest public investments in quantum technologies in the world. The recommendations of the GO-Science report published midway through the programme have been broadly accepted and progress has been made towards delivering many of the recommendations, such as the Blackett review exploring the UK's dependence on global navigation satellite systems (GNSS).[6] There are several outstanding recommendations, including those relating to the establishment of innovation centres to promote technology commercialisation, and the creation of an overarching coordinating body, that should form part of the next tranche of funding.

4. The dedicated overarching body was recommended to more effectively coordinate activities at a national level across the UKNQT programme, as it grows in scope. The coordination and unified structure provided by UKRI, once established, should enable funding to be allocated more strategically, to better capitalise on areas of UK strength and derive the greatest possible benefit, in contrast to the current separation of funding delivered through EPSRC and Innovate UK. This should have the added

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[1] Government Office for Science, 2016. *The Quantum Age: Technological Opportunities* https://www.gov.uk/government/publications/quantum-technologies-blackett-review

[2] Defence Science and Technology Laboratory, 2016. *UK Quantum Technology Landscape 2016* http://uknqt.epsrc.ac.uk/files/ukquantumtechnologylandscape2016/

[3] Parliamentary Office of Science and Technology, 2017. *POSTnote 552 Quantum Technologies* http://researchbriefings.parliament.uk/ResearchBriefing/Summary/POST-PN-0552

[4] Elsevier, 2017. *International Comparative Performance of the UK Research Base 2016* https://www.gov.uk/government/publications/performance-of-the-uk-research-base-international-comparison-2016

[5] Comparator countries are Brazil, Canada, China, France, Germany, India, Italy, Japan, Russia, South Korea, UK, USA.

[6] Government Office for Science, 2018. *Satellite-derived Time and Position: A Study of Critical Dependencies* https://www.gov.uk/government/publications/satellite-derived-time-and-position-blackett-review

benefit of providing more seamless support to projects spanning a range of technology readiness levels.

The relative contribution/support from government, researchers and businesses needed to make quantum technologies a success

5. The nature of quantum technologies – enabling technologies rooted in basic research – means that their successful commercialisation will require a bespoke balance of funding, able to maintain a vibrant research base while driving the development of devices and components integral to larger products.

6. To ensure that progress towards a successful UK quantum technologies industry does not stall, it is essential that fundamental quantum physics research underpinning the development of quantum technologies that is funded outside of the UKNQT programme is supported. EPSRC acknowledged the need to support the research underpinning quantum technologies as part of its recent 'Balancing Capability' research prioritisation exercise and assigned 'maintain' status to a number of quantum-related fields in its portfolio[7], indicating that those fields are to be maintained at the current funding level. This level of support should continue to be reviewed periodically, in consultation with the research communities. It may be that as new technological solutions and devices are developed, new avenues for basic research appear.

7. The development of quantum technologies is a long-term challenge – technology readiness levels vary but predicted timescales to market can be as much as 25 years[8] – and the pace and scale of international competition has increased since the publication of the GO-Science report. As the initial phase of the UKNQT programme comes to an end in 2019, further investment will be required to secure and strengthen the UK's position, particularly in light of significant investment from established and emerging competitors such as the US (which has a large research base, but less well developed quantum technology applications) and China (where total research activity is doubling over periods shorter than four years[2]). To cut off funding after one round and expect industry to step in would be self-defeating. While progress to date has been positive, the development timescale for many disruptive technologies is much longer than the five-year timescale of the UKNQT programme (for example, in 2015, the National Quantum Technologies Roadmap stated that it is expected to be 10 to 20 years before commercial quantum computing solutions are widely available[8]). Commitments to a new round of investment should be made as soon as possible, as any perceived drop off in the level of financial support in the UK could lead to the loss of expertise currently in the UK and deter potential talent and investors, both within the UK and from overseas.

8. At the early stages in their development, quantum technologies are unattractive to private investors and rely on public support to leverage and de-risk private investment, and progress from lab to production line. As technologies develop, it would be expected that private sector investment will increase.

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[7] Engineering and Physical Sciences Research Council. Research areas [accessed 8 March 2018] https://www.epsrc.ac.uk/research/ourportfolio/researchareas/

[8] Quantum Technologies Strategic Advisory Board, 2015. *A Roadmap for Quantum Technologies in the UK* https://www.epsrc.ac.uk/newsevents/pubs/quantumtechroadmap/

9. There is a further role for public bodies to play in facilitating private sector investment, through real-world demonstrator projects showing the potential of quantum technologies to outperform existing solutions. The mutual benefits offered are already recognised and taken up in the defence sector, but similar demonstrator projects could be offered to address other public sector challenges, for example, in infrastructure construction and the transport sector, potentially funded through the Small Business Research Initiative or Industrial Strategy Challenge Fund.

The current state of the UK quantum industry and its potential going forward, including particular strengths and challenges

10. There is a growing quantum-enabling industry in the UK, predominantly made up of suppliers of the components and subsystems developed for integration in larger systems. Larger systems integrator companies need to be encouraged into the sector, in order to further expand the UK industry and bring full quantum technology systems to market, and this could be achieved through demonstrator projects, as mentioned above.

11. To fully realise the economic and societal benefits of quantum technologies, the UK needs to convert its strong research base into commercial products, by deepening connections between academia and industry, and capitalising on relevant industrial strengths (for example, in photonics). Industrial engagement in the four hubs established by the UKNQT programme has been positive, as demonstrated by the growing number of industrial partners (with the Hub for Sensors and Metrology alone working with over 100 industry partners and attracting over £30 million of additional funding[9]), with the aim of encouraging industry to engage at an earlier stage in the technology development process. A clear plan to increase the level of meaningful industrial engagement should be central to any future quantum technologies programme.

12. The innovation centres recommended in the GO-Science report could form a part of an industrial engagement plan, providing a proven platform for such engagement and a focus for academia and industry to work together towards industrial challenges related to the exploitation of quantum technologies. Such centres could also provide a useful mechanism for improving quantum technology-related skills throughout the supply chain.

13. In common with other areas of research and innovation, Brexit presents some challenges to the development of quantum technologies. Clarity is needed regarding arrangements following the UK's exit from the European Union, if the quantum technologies community is to avoid losing talent and access to international research programmes. The UK must continue to be seen as a major player and supporter of quantum technologies in order to attract international investors.

What oversight or regulation is needed

14. As an emerging technology, the regulatory environment surrounding quantum technologies needs to strike a balance between being both flexible enough to foster

[9] UK National Quantum Technology Hub for Sensors and Metrology, 2017. *Annual Report 2015-16* https://www.quantumsensors.org/wp-content/uploads/2017/08/qt-hub-annual-report-2015-2016-web.pdf

innovation and deployment in the early stages, while also instilling confidence in performance in investors and the public.

15. As new technologies move closer to market, the UK should play a role in the development of international standards to represent the interests of UK developers, working closely with international partners, and this activity must be prioritised. Standardisation is particularly crucial to delivering uptake of quantum technologies, which involve new and unconventional concepts that must be similarly understood across academia and industry through a common language.
16. As with any emerging technology, there is a need for responsible research and innovation, and proactive engagement with a wide range of stakeholders including the public should be embedded within any quantum technologies programme to ensure research is socially desirable and undertaken in the public interest.

Potential barriers for developing quantum technologies, and how these might be overcome

17. The development of quantum technologies requires a highly skilled and multidisciplinary workforce, with expertise in fields including engineering, manufacturing and business, as well as physics.[1] Currently this demand is largely at PhD level, which is supported by EPSRC's investment in quantum-related Centres for Doctoral Training and Training and Skills Hubs, but as technologies mature there will be an increasing demand for technical and engineering skills. The growing STEM skills shortage in the UK may present a barrier to the successful development and commercialisation of quantum technologies.
18. A significant proportion of the skills need will be at engineer level, so focus should be placed on equipping current and future engineers with skills relevant to quantum technologies. An example of such an initiative is the Quantum Technology Enterprise Centre, which provides relevant business and engineering and design training to potential quantum technology entrepreneurs. However, training support is needed on a larger scale and at differing entry points – for example, at apprenticeship level. Any new quantum technologies programme must include a strategy for skills development that addresses the future needs of the entire quantum technologies supply chain, and should not be limited to Centres for Doctoral Training.
19. Low levels of business investment in research and development (R&D), which is traditionally used to bridge the technology readiness level gap between academia and industry, must be taken into account and addressed as part of any future quantum technologies programme. The innovation centres recommended in the GO-Science report could provide access to the infrastructure and resources needed to stimulate business investment in R&D and increase absorptive capacity, as well as support wider efforts to meet the Government's R&D investment target of 2.4% of GDP.
20. Industry needs access to appropriate test infrastructure (and demonstrator projects, as mentioned above) to successfully demonstrate the step change in performance offered by quantum technologies and drive market uptake. Accelerated adoption can yield economic and societal benefits for the UK and put UK companies in a globally competitive position to exploit export markets. However, a clear idea of the most

fruitful opportunities for market application of quantum technologies is needed before any large-scale investment in infrastructure.

What research priorities there should be for quantum technologies and their possible uses, and who is best placed to undertake/fund that work

21. Quantum technologies research is still a relatively young field and care must be taken to avoid limiting future success by concentrating activity too narrowly at this stage. Research funding should support a broad base that provides the agility to respond to the future emergence of as-yet unrecognised areas of technological development and market application.

22. Any future quantum technologies programme should include a review of the landscape to identify any emerging areas that were not included within the scope of the original UKNQT programme that may benefit from access to programmatic support and strategic alignment.

The role of international collaboration in quantum technology research and development; and the risks and opportunities of Brexit in this area

23. The successful development of quantum technologies in the UK will require continued access to overseas talent, funding (both public and private), markets and regulatory influence post Brexit.

24. Many leading researchers in the UKNQT programme are non-UK EU citizens, who have come to the UK because of the strength of the research base and underpinning public funding. In light of existing STEM skills shortages, the sector needs access to a wide pool of academic and technical talent across Europe, and the rest of the world, to ensure the best possible outcomes for the UK. Any future immigration system must be favourable to scientists and engineers coming to the UK from EU (and non-EU) countries.

25. Quantum technologies research is a highly collaborative endeavour. Until commitments are made regarding access to successor programmes to Horizon 2020, the UK's continued involvement in collaborative EU quantum research programmes, including the new €1-billion Quantum Technology Flagship, is uncertain. There is a risk that, without the collaboration enabled by such participation, UK research programmes will become disengaged from EU programmes. Countries including Austria, Germany and Hungary have announced national quantum technologies programmes since the EU's Flagship was announced,[10] so it is clear that activity in the field, and consequently opportunities for UK involvement, are expanding.

26. The UK must preserve its status as a leading international player in quantum technologies to attract international businesses and increase its share of foreign private investment, and ultimately accelerate the translation of quantum research into commercial benefit for the UK. Firm commitments regarding future public investment and trade agreements are needed to avoid funds being redirected to countries with weaker research bases but more certain long-term prospects.

27. Quantum technologies research is already a global endeavour and there are many fruitful collaboration opportunities being pursued outside of the EU, with Australia,

[10] Nature, 2017. Europe's billion-euro quantum project takes shape https://www.nature.com/news/europe-s-billion-euro-quantum-project-takes-shape-1.21925

Canada, China, Japan and the US all having strong quantum technologies research programmes, in addition to those within Europe.

Any challenges from potential civil/military 'dual-use' applications of the technologies, and how these can be addressed

28. Many quantum technologies are 'dual use', having both civil and military applications, due to their applications in fields such as navigation and communication. The military plays an important role as an early adopter of quantum technologies, helping to de-risk development for investors and propel technologies into the mainstream commercial market. For example, quantum gravity sensors that can be used to 'see' underground are of interest to the defence community, but could be of equally high value to civil applications – for example, locating underground pipelines during construction projects or mapping oil and gas deposits. Such civil engineering applications are now under development in projects involving UK companies.
29. At the same time, restrictions preventing some military-developed quantum technologies from being shared with commercial developers, due to security concerns, can stifle their deployment in wider society. The defence community must avoid restricting wider access to technologies unless absolutely necessary, particularly in light of the mutual benefits offered by commercial application in terms of additional leveraged funding.
30. Dual-use status may impose restrictions on the trade of some quantum technologies – in particular, the US International Traffic in Arms Regulations (ITAR) place strict limitations on the use of US-developed defence-related knowledge and technology, including those of relevance to quantum technologies.[2] Consideration must be given to the possibility that components procured from the US for UK-developed quantum technologies may not be available in the future, if the US chooses to restrict them, and establishment of a domestic supply chain is consequently of even greater importance. Training in the issues associated with both US and UK export controls for dual-use technologies has been delivered through the UKNQT programme to mitigate potential risks, and should be continued as part of any future programme.

Any potential societal implications – positive and negative – of the development of quantum technologies, including on health, security, privacy or equality

31. As with most technological advances, there is potential for misuse of quantum technologies and some bring privacy and security implications alongside the significant positive benefits. For example, future quantum computers should complete tasks in a few seconds that would take today's supercomputers millions of years – including the factorisation of large numbers that underpins the security of commonly used encryption techniques, rendering them vulnerable to attack.[1] However, quantum encryption techniques under development, such as quantum key distribution (which uses quantum mechanical principles to detect any third-party interception), should significantly improve the security of communications and protect financial, government and personal data from hacking by future computers.
32. Risks posed by quantum technologies have the potential to be managed through existing structures (for example, those governing the use of data) and should be taken into account as any new legislation in relevant areas is developed, and failure to develop capability in these areas could leave the UK vulnerable to external attack.

33. Evidence concerning public opinion of quantum technologies in the UK is limited.[11] The results of an EPSRC-commissioned public dialogue on quantum technologies, carried out as part of the UKNQT programme, are expected to be published later in 2018.[12] Early indications from this work are that participants were supportive of public investment in quantum technologies to position the UK as a leader in the field, with excitement regarding the potential benefits offered and a measured view concerning the potential for misuse. Participants viewed risks as extensions to existing risks (such as those concerning privacy and security), with the inclusion of quantum technologies into wider debates on technological advancements being an appropriate way forward.

34. As with any emerging technology, it is essential to openly consider any societal impacts potentially arising from quantum technologies and proactively engage the public as early in the development process as possible to ensure outcomes are aligned with the values of society, and such engagement should be built into any future quantum technologies programme, in line with good responsible research and innovation practice.

About the Institute of Physics

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For more information, contact
Alex Connor, head of policy (alex.connor@iop.org)

[11] Sciencewise, 2014. *Public Attitudes to Quantum Technology* http://www.sciencewise-erc.org.uk/cms/assets/Uploads/Quantum-Technology-Social-IntelligenceFINAL.pdf
[12] Quantum Communications Hub. News [accessed 9 March 2018] https://www.quantumcommshub.net/news/