Quantum Computing & Simulation Hub

Quantum Computing in the UK today

Dr Rupesh Srivastava, User Engagement

May 2021

For BCS Berkshire

Part of UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME

Funded by UKRI Engineering and Physical Sciences Research Council

What we'll cover

1. What is Quantum Computing and why the excitement?
2. The status and outlook for Quantum Computing & Simulation
3. The UK QT Programme
4. How to engage with Quantum Computing

Question: *When will Quantum Computing make an impact?*

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"Quantum information is a radical departure in information technology, more fundamentally different from current technology than the digital computer is from the abacus."

W. D. Phillips
Nobel Laureate 1997

Saunpan Abacus

Modern Laptop Computer

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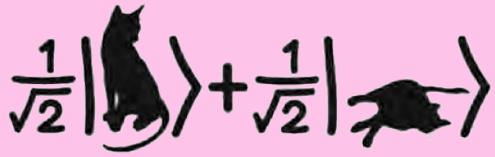
A recent history of science and computation

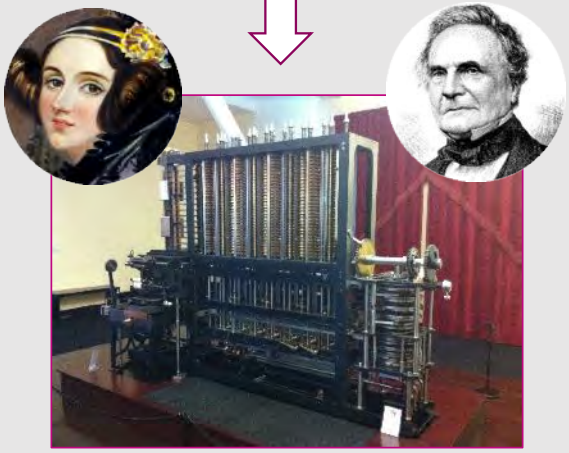
For BCS Berkshire Members

SCIENCE



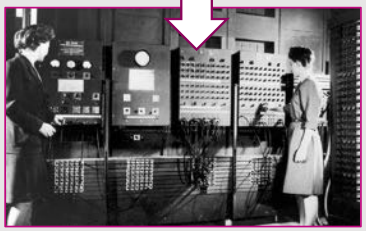
19th • • • 20th • • • 21st • Quantum 2.0

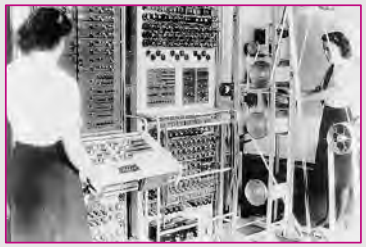
COMPUTERS



Babbage Difference Engine

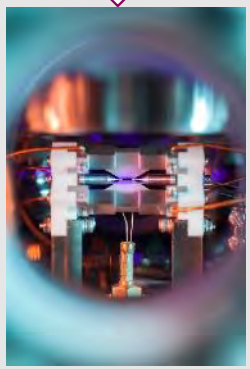
ENIAC





Colossus at Bletchley Park

Summit Supercomputer



QCS Hub Research

Classical Physics influences the design of the latest chips

Some components may use quantum principles in their operation – but the chip does not use quantum for computation

32-core AMD Epyc (2017)
19,200,000,000 transistors (14 nm)

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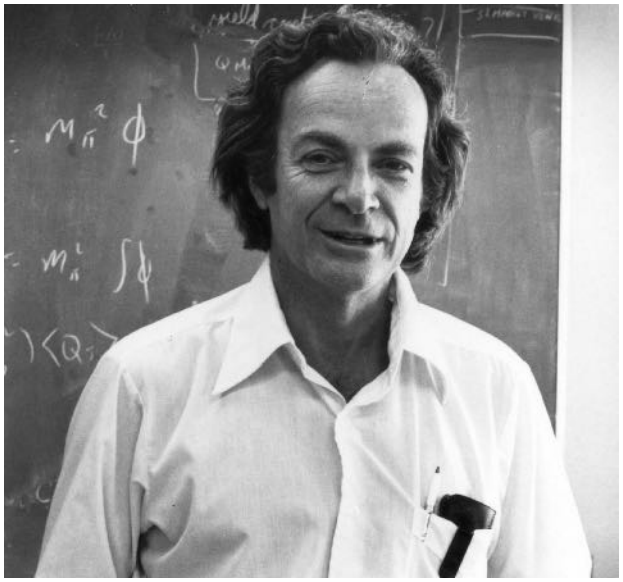
BREAKING NEWS 2021

Why build a quantum computer?



Richard Feynman
Nobel laureate

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The first question is, What kind of computer are we going to use to simulate physics?

But the physical world is quantum mechanical, and therefore the proper problem is the simulation of quantum physics.

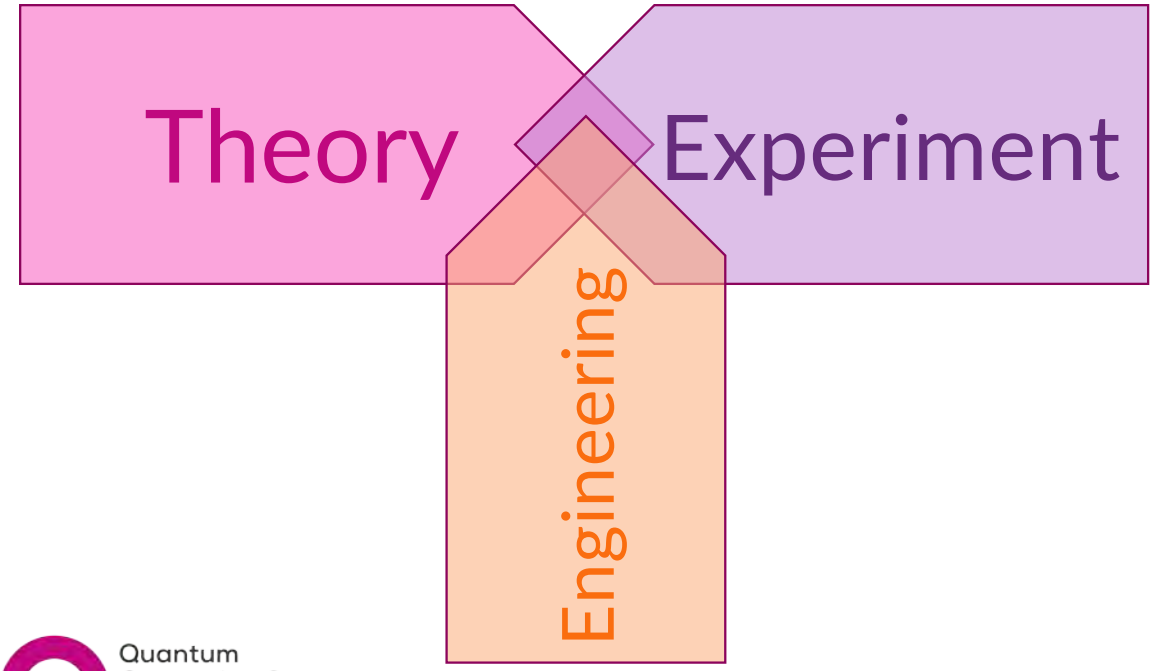
Can you do it with a new kind of computer, a quantum computer?

… It's not a Turing machine, but a machine of a different kind.

Why build a quantum computer?

Opportunity	New era of discoveries
Motivation	Moore's Law can't continue forever
Timing	Because now we can!* * 40 years later

Timing – is key



You need a happy confluence of theory, experiment and engineering

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Timing – what about now?

Theory

Experiment

Engineering

It’s just possible to engineer a quantum computer

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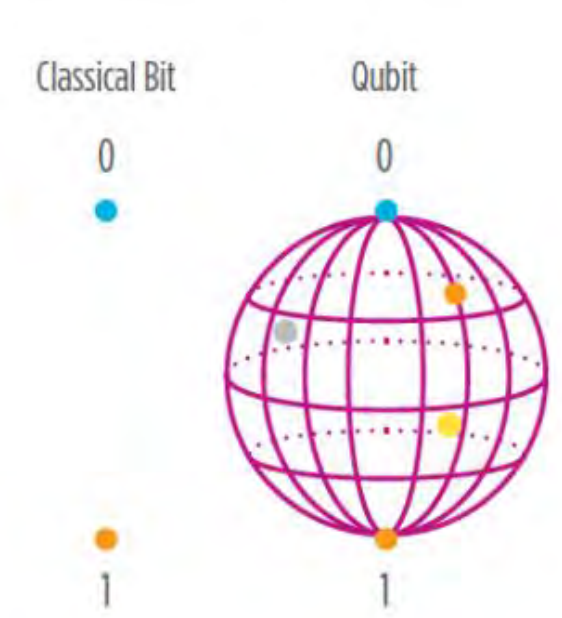
Quantum Computing and Qubits

Use and manipulate phenomena of quantum physics

- Superposition:
  - Qubits being in multiple states at the same time, e.g. ‘0’ and ‘1’
- Entanglement:
  - Grouped behaviour of multiple ‘qubits’
- Interference
  - Utilising wave properties to amplify the “right” answers and cancel out the “wrong” ones



(Source: Blackett Review, 2017)

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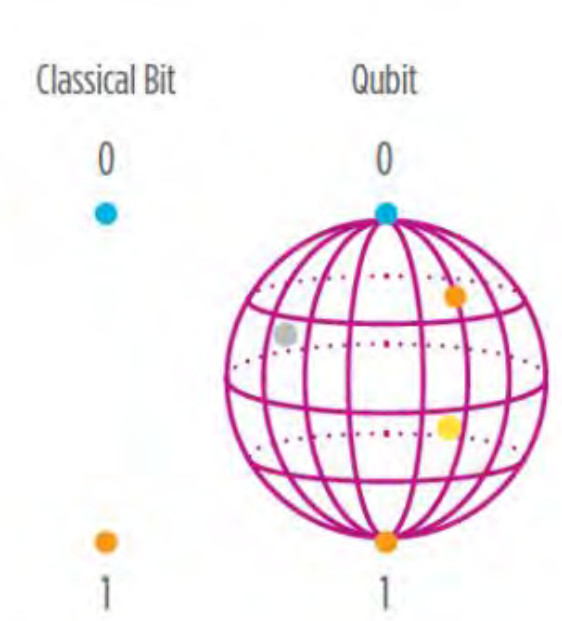
Quantum Computing and Qubits

In order to simulate N qubits requires 2^N classical bits

N	2^N	Comment
3	8	easy!
20	~$1x10^6$	laptop
50	~$1x10^{15}$	supercomputer
300	~$2x10^{90}$	> atoms in known universe



(Source: Blackett Review, 2017)

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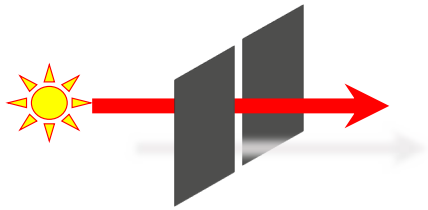
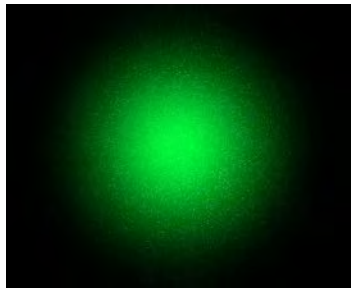
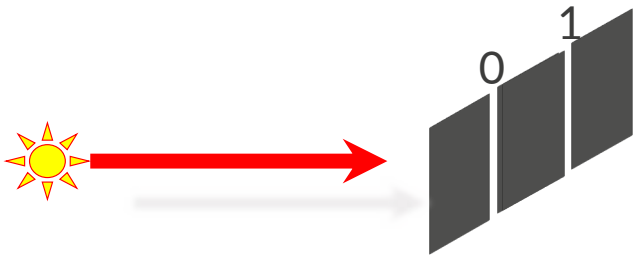
Illustrating superposition with light

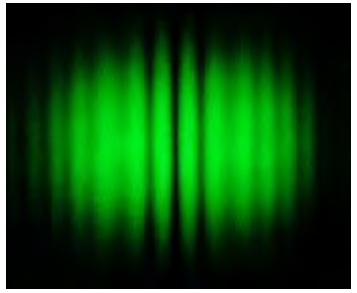


A ‘photon’ is a particle of light

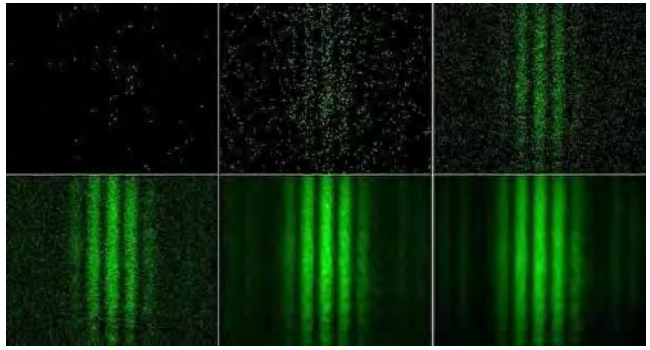




Which path?



Quantum physics says that even a single photon can pass through both slits



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A single photon encodes a “qubit” – a superposition of “0” + “1”

Why the excitement?

- A Quantum Computer's power doubles with every qubit added
  - Speedups beyond the capability of future digital computing
  - Able to solve 'hard problems'
  - Able to mimic real world quantum systems
- Expected high impact on most industry sectors, national economies, national security and research and discovery
- Estimated impact, $450-800bn operating income/yr*

*(Source: Where will Quantum Computer Create Value – And When?, BCG, 2019)

Source: The Business Potential of Quantum Computing, BCG @ Q2B, Dec 2019

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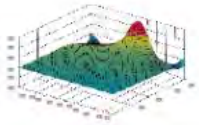
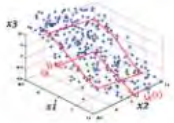
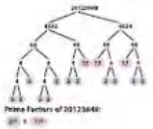
A variety of application areas… starting with M

- Medicine
- Materials
- Molecules
- Modelling & Simulation
- Money Markets
- Machine Learning
- Mobility
- Manufacturing
- Mass Communication
- Mysteries of the universe

Application areas (cont')

Problem archetype	Useful for ...	Industry applications
Combinatorial optimization 	... minimizing or maximizing an objective function such as finding the most efficient allocation of resources, or the shortest total distance among a set of points (e.g. the travelling salesman problem)	• Network optimization for airlines • Supply chain and logistics optimization • Portfolio optimization in financial services
Differential equations 	... modeling the behavior of complex systems involving fundamental laws of physics (e.g. Navier Stokes for fluid dynamics) and chemistry	• Fluid dynamics simulations for automotive and aeronautical design, and for medtech • Molecular simulation for specialty materials design and for drug discovery
Linear algebra 	... machine learning tasks involving matrix diagonalization such as clustering, pattern matching and principal components analysis (PCA), as well as support vector machines (SVMs) which are ubiquitous in applications across industries	• Risk management in quantitative finance • DNA sequence classification • Marketing and customer segmentation
Factorization 	... cryptography and computer security where the most common protocols today (e.g. RSA) rely on the infeasibility (for classical computers) of factoring the product of two large prime numbers.	• Decryption and codebreaking, e.g. for governments

(Source: The Business Potential of Quantum Computing, BCG, 2019)

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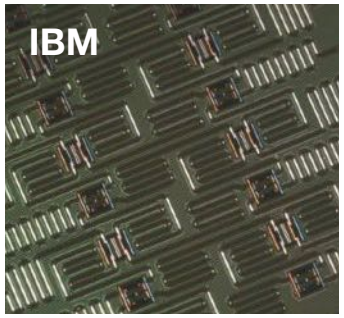
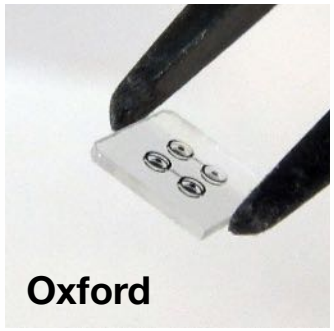
A variety of ways to build quantum computers

Superconducting circuits	Ion-traps	Photonics	Solid state	Cold atoms	Nano wires
Oxford Quantum Circuits	Oxford Ionics	Duality Photonics	Quantum Motions	Cold Quanta	Microsoft
IBM	Universal Quantum	ORCA Computing	Intel	Atom Computing	
Google	IonQ	PsiQuantum	Quantum Brilliance	Pasqal	
Rigetti	Atos	Xanadu			
Intel	Honeywell	QuiX			
Alibaba					

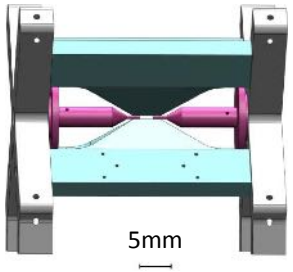
Quantum computing: some qubit technologies

Superconducting

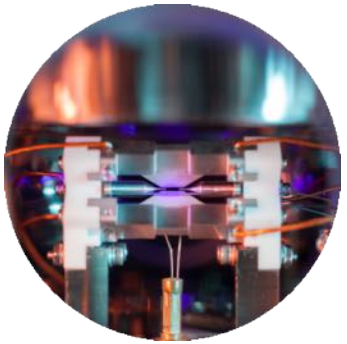


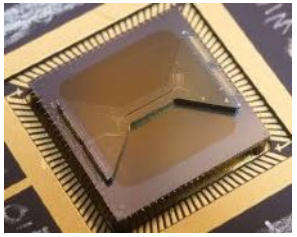


Ions

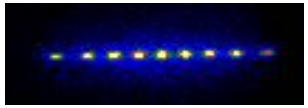


Macroscopic
“blade” trap





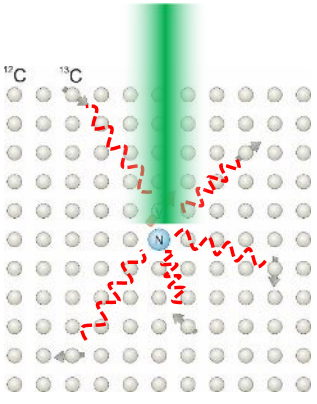
Microfabricated
“chip” trap



9 qubit
“memory register”

Diamond

~1 cm



~ 2 nm

The available NISQ's

- IBM Q, 21 QC's online (free or paid), up to 65 qubits – roadmap to 1000+ by 2023
- Google Sycamore, access on request, up to 54 qubits
- Rigetti, access on request or via AWS Braket, up to 32 qubits
- IonQ, access on request or via AWS Braket, up to 11 qubits
- Honeywell, access TBA, up to 10 qubits
- QuTech's Quantum Inspire, open access with up to 5 qubits

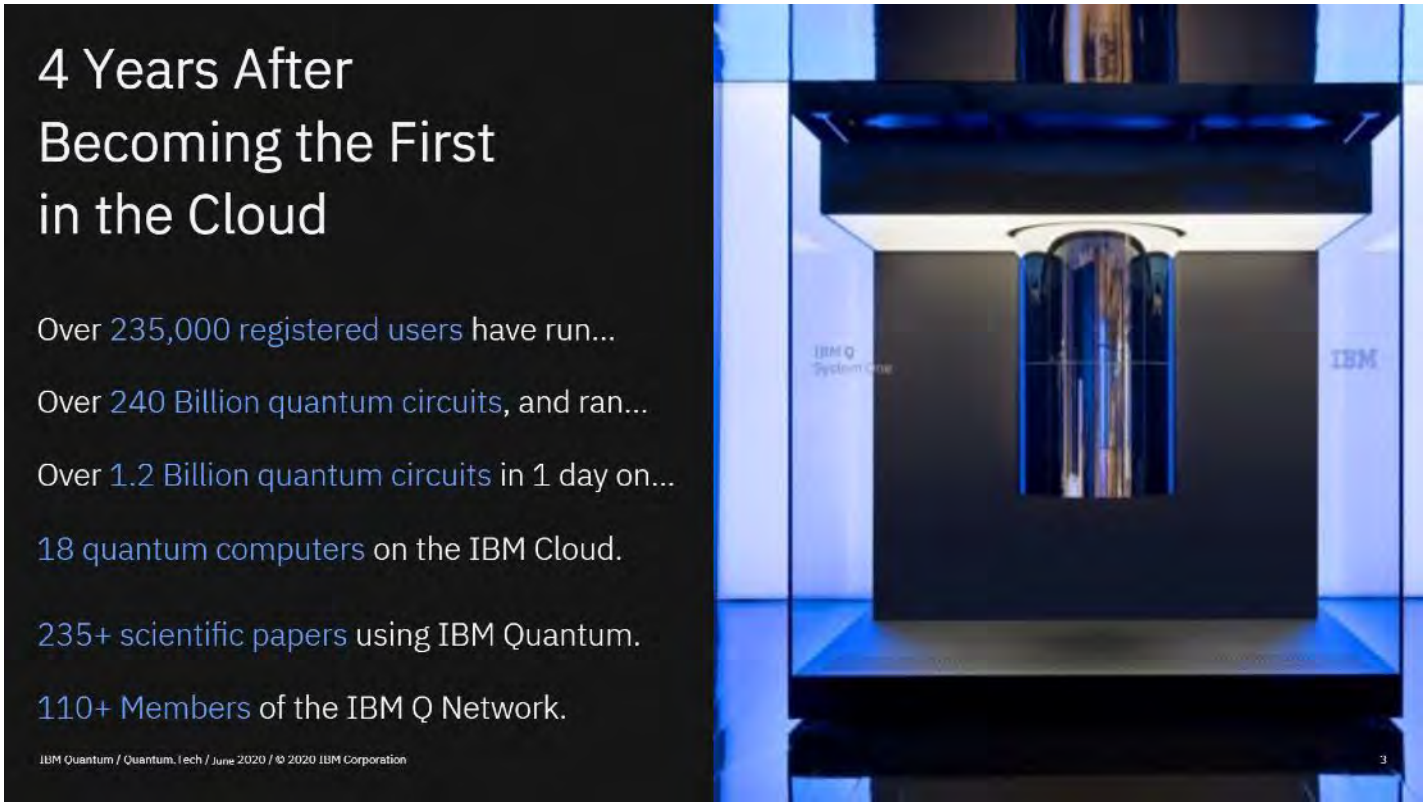
30+ new ventures worldwide building quantum computer systems

... including 6 in the UK

Announced:

- UK National Quantum Computing Centre
- Finland VTT to acquire a National Quantum Computer
- Germany (€2b, France (€1.8b), India ($1b)

IBM Q as an example



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(Source: IBM, 2020)

What about usefulness: Google's Quantum Supremacy

- Google used its 54* qubit Sycamore processor
- Non-error-corrected quantum computer (i.e. a NISQ)
- In collaboration with NASA ran a well defined computational task (RNG)
- The experiment took 200 seconds
- Google determined that it would take the world's fastest supercomputer 10,000 years to produce a similar output

* with 53 qubits working

- IBM's response included a proposal that would use Summit, the 2nd most powerful supercomputer, using 250 petabytes of hard-disk space running for 2.5 days

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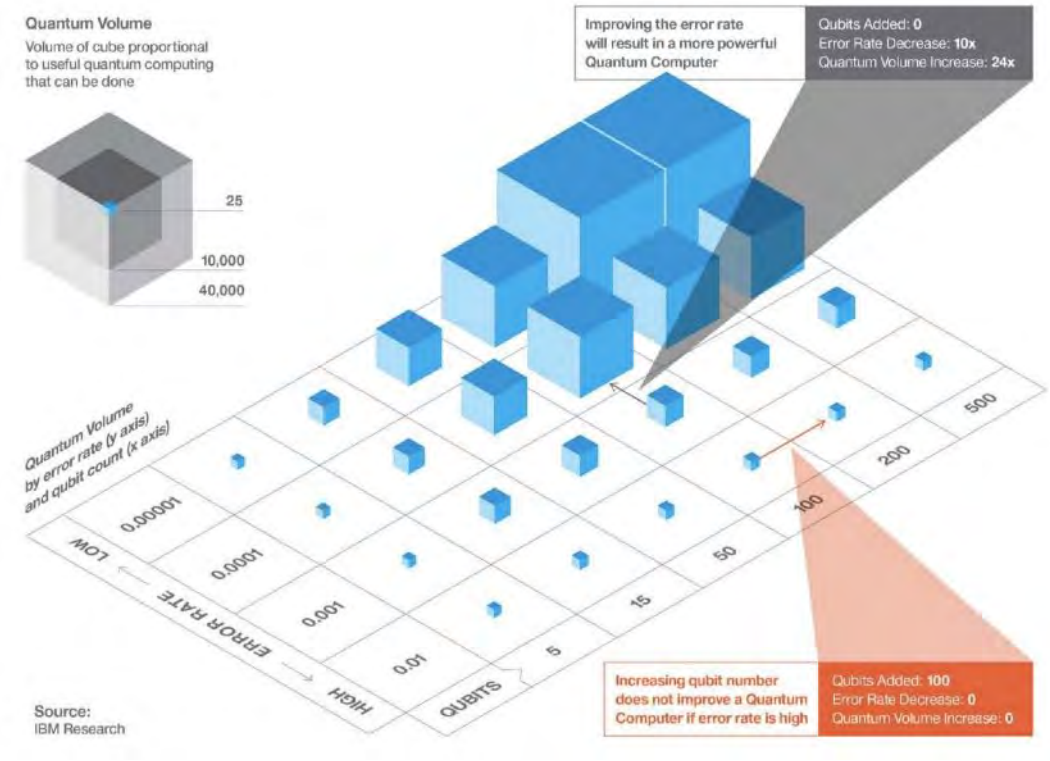
But not so fast …

- QC's and Qubits are fragile, difficult to control, difficult to read, full of errors, slow and expensive
- Quantum Error Correction (QEC) enables a Universal Fault Tolerant Quantum Computer (UFT) with 'logical qubits' but requires large numbers of physical qubits
- The QEC 'overhead' depends on the quality of the physical qubits



(Source: IBM, 2018)

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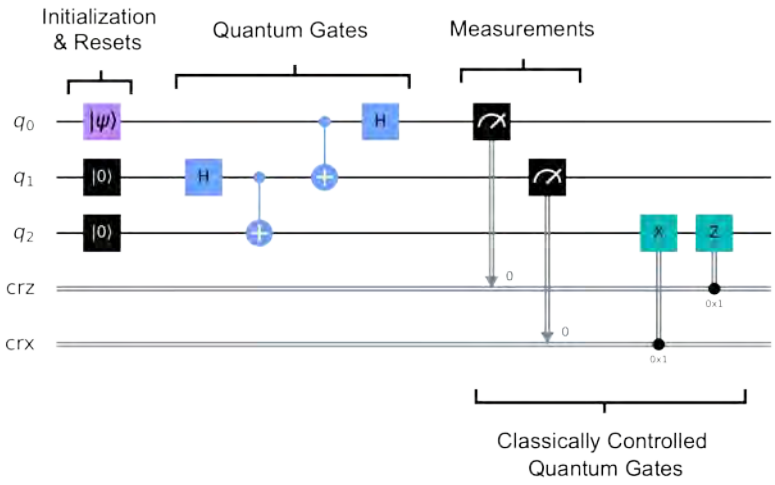
The Development Tools and Environments

- IBM Quantum Experience and Qiskit
- Cirq and ProjectQ, promoted by Google AI
- Rigetti's Forest platform with Quil
- Amazon's Braket multi-vendor platform and environment
- Microsoft's Quantum Development Kit including Q#
- Atos/STFC Quantum Learning as a Service
- QuEST open source Quantum Simulation Kit from Oxford
- Deltaflow, River Lane's cross platform operating system
- Quantum Inspire platforms from QuTech in Delft
- Zapata's Orquestra, a unified quantum operating environment
- Xanadu's Pennylane and Strawberry Fields python libraries
- Baidu's Paddle Quantum and many more …



Source: qiskit.org

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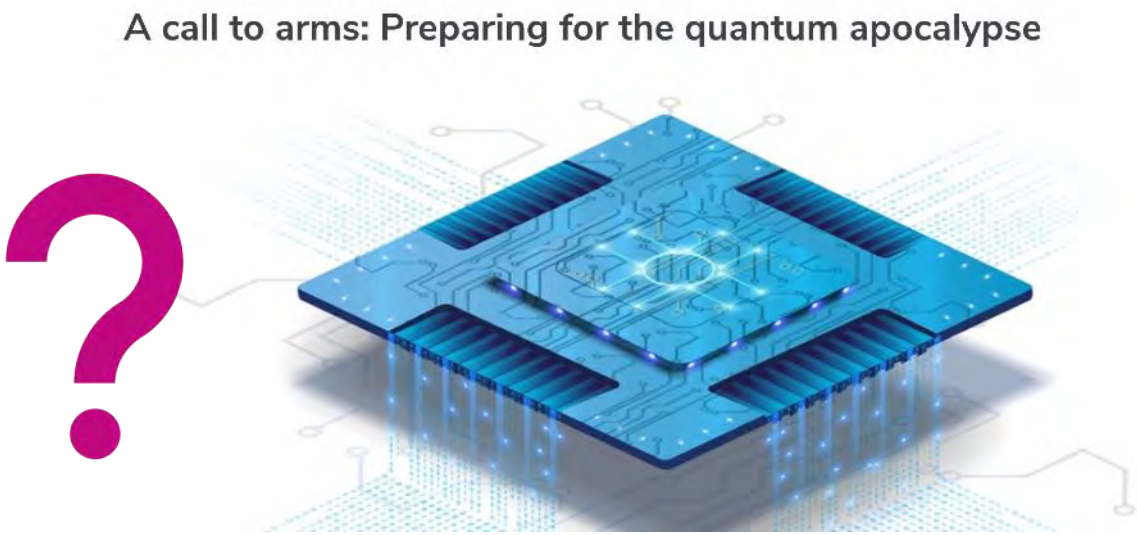
One more thing … encryption

Relies on factoring prime numbers.

What two prime numbers produce

- 15
- 82,249
- $2^{82,589,933}$ (24,862,048 digits)



Source: Security Magazine, September 22, 2020

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One more thing … encryption

- NISQ's are not a threat to most current encryption methods – but UFT Quantum Computers are!
- Key risks:
  - Current data can be stored for future decryption
  - Re-encrypting existing data takes time
  - Post quantum cryptography – is it truly resilient?
- From the National Cyber Security Centre on Quantum Safe Cryptography (QSC):

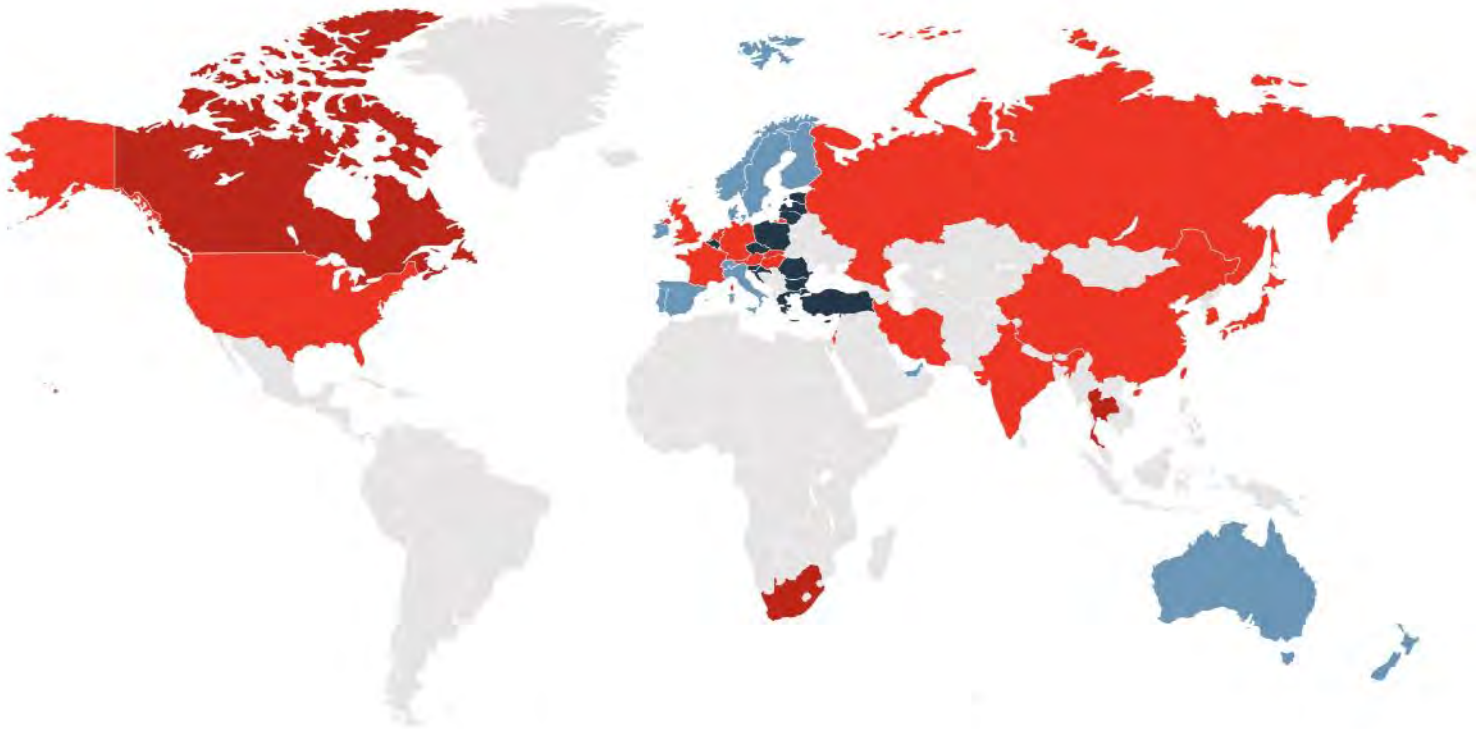
Early adoption of non-standardised QSC is not recommended.

The NCSC recognises the serious threat that quantum computers pose to long-term cryptographic security. QSC using standards-compliant products is the recommended mitigation for the quantum threat, once such products become available.

https://www.ncsc.gov.uk/whitepaper/quantum-safe-cryptography

Quantum Technologies R&D

Source: CIFAR – **A QUANTUM REVOLUTION**



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Quantum Technologies in the UK

- Long history of outstanding science and QT pioneers
- A world-class advanced technology sector
- A UK National QT Programme since 2013
- Blackett Report in 2017
- HoC Science & Technology Committee Report, 2018
- UK QTP Phase 2 started in 2019

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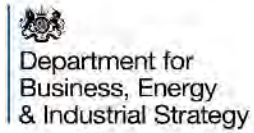
UK National QT Programme, 10 years, £1 billion

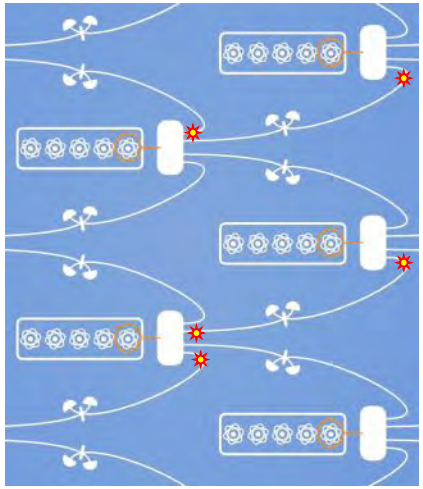
- Four Quantum Technology Hubs
  (Sensing, Imaging, Communications, Computing & Simulation)
- Skills and Training programme
- Industrial Strategy Challenge Fund for Industry-led Innovation
- National Quantum Computing Centre
- Strategic Partnerships and International participation
- 10-year Quantum Strategy led by UK Government



2014-2019 Achievements

NQIT Networked Quantum Information Technologies

- Photonically-networked ion trap architecture: node-node connectivity demonstrated with a world-leading combination of rate and fidelity
- New benchmarks for speed and precision of quantum logic operations
- Modular quantum optical circuits for processing and simulation
- Unique deterministic NV centre-writing capability
- Unique superconducting qubit architecture
- Blind quantum computing and verification concepts
- World's fastest emulator, QuEST
- Verifiable Quantum Random Number Generator
- Responsible Research and Innovation studies in QC
- Vibrant network of over 100 companies engaged
- Encouraged and supported 7 spinouts
- International advocacy and industrial engagement
- Skills and training in quantum science, technology and entrepreneurship



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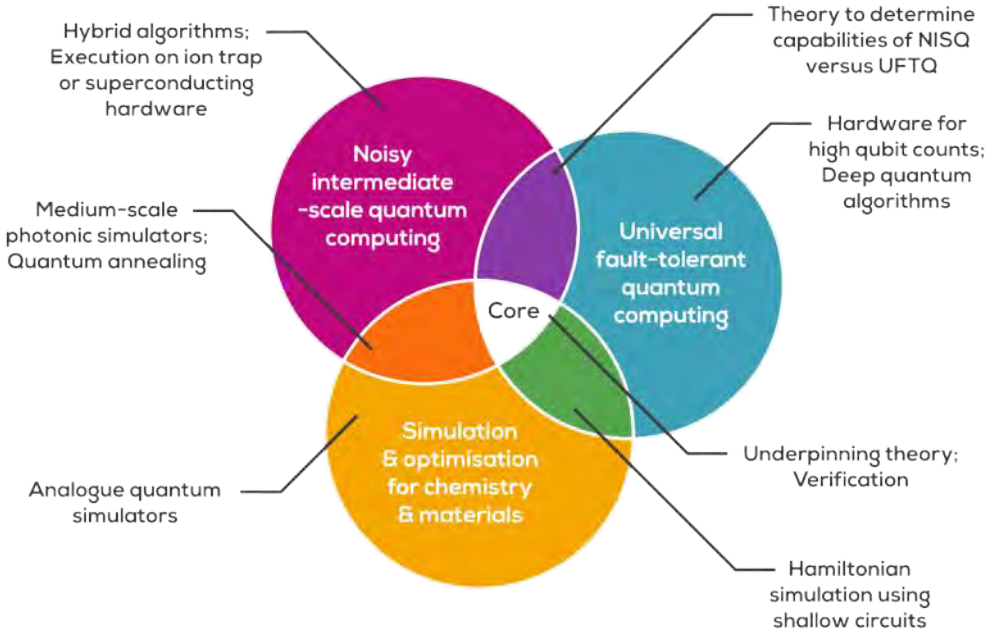
UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME

2019 – 2024 The QCS Hub

- The UK National Quantum Computing & Simulation Hub
- Five-year research and technology programme with £25m funding, following on from the 2014-2019 NQIT Hub
- Objective: to create a quantum information economy in the UK
- Focus on QC&S technologies, both near-term (NISQC) and long-term (UFTQC)
- 17 participating universities, 43 Co-Investigators, led by Oxford
- 28 companies and organisations offering support
- Supporting the UK National Centre for Quantum Computing



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UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME

QCS Hub Partners

Academic partners

Cardiff University
Prifysgol Caerdydd
University of Cambridge
University of Southampton
Royal Holloway University of London
Imperial College London
University of Glasgow
Warwick
The University of Sheffield.
The University of Edinburgh
University of Sussex
University of Bristol
University of Bath
Durham University
University of Strathclyde Glasgow
UCL
University of Surrey
University of Oxford

Industrial partners

- Airbus Defence & Space
- BP
- BT
- Cambridge Quantum Computing Limited
- Creotech Instruments SA
- D Wave Systems
- Defence Science & Tech Lab
- Element Six
- Fraunhofer Institute
- GlaxoSmithKline
- Gooch & Housego
- Heilbronn Institute for Mathematical Research
- IQE Ltd
- Johnson Matthey
- M Squared Lasers
- National Cyber Security Centre
- National Physical Laboratory
- Oxford Instruments Ltd
- Oxford Quantum Circuits
- Oxford Sciences Innovation
- QinetiQ
- Quantum Machines
- Quantum Motion
- QxBranch
- Rigetti & Co
- Rolls-Royce
- The Alan Turing Institute
- Trakm8 Ltd

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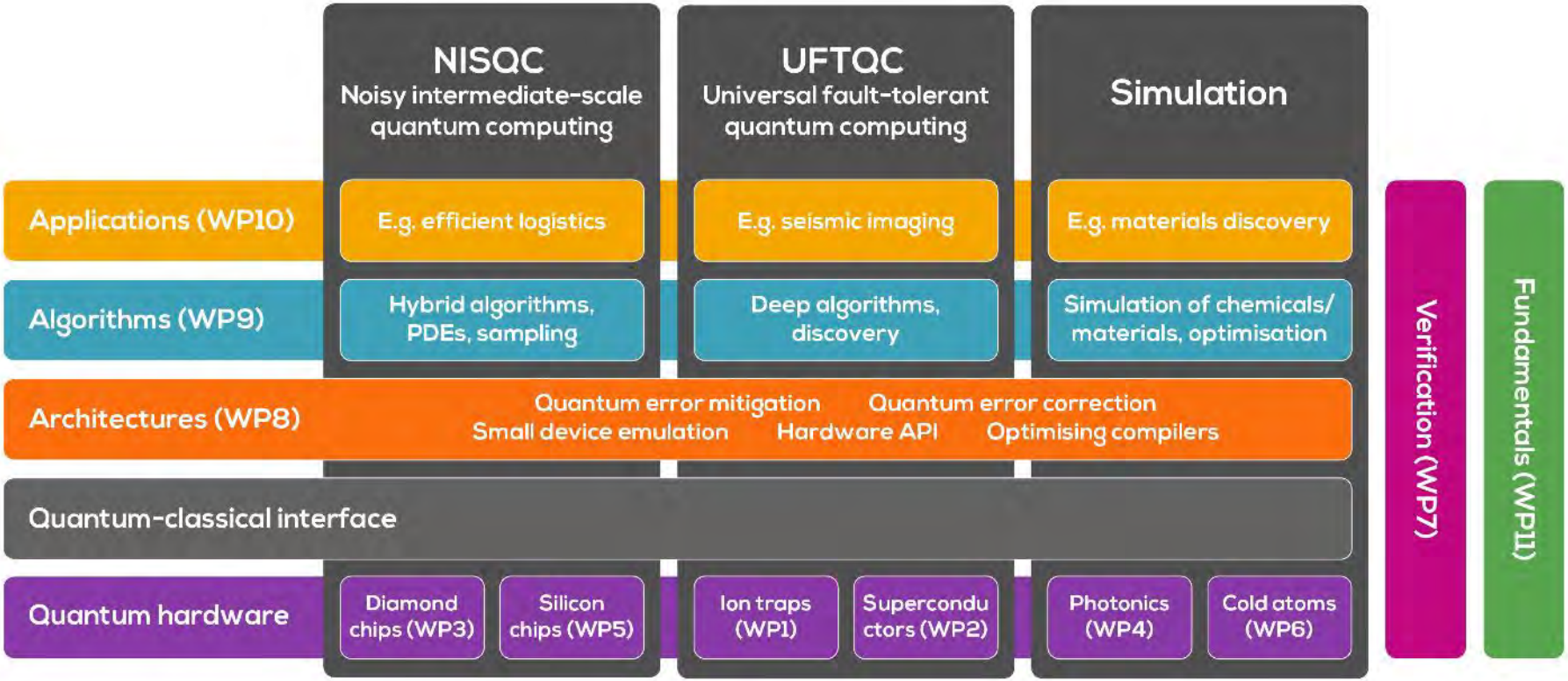
UK National Quantum Technologies Programme

QCS Hub Work Programme



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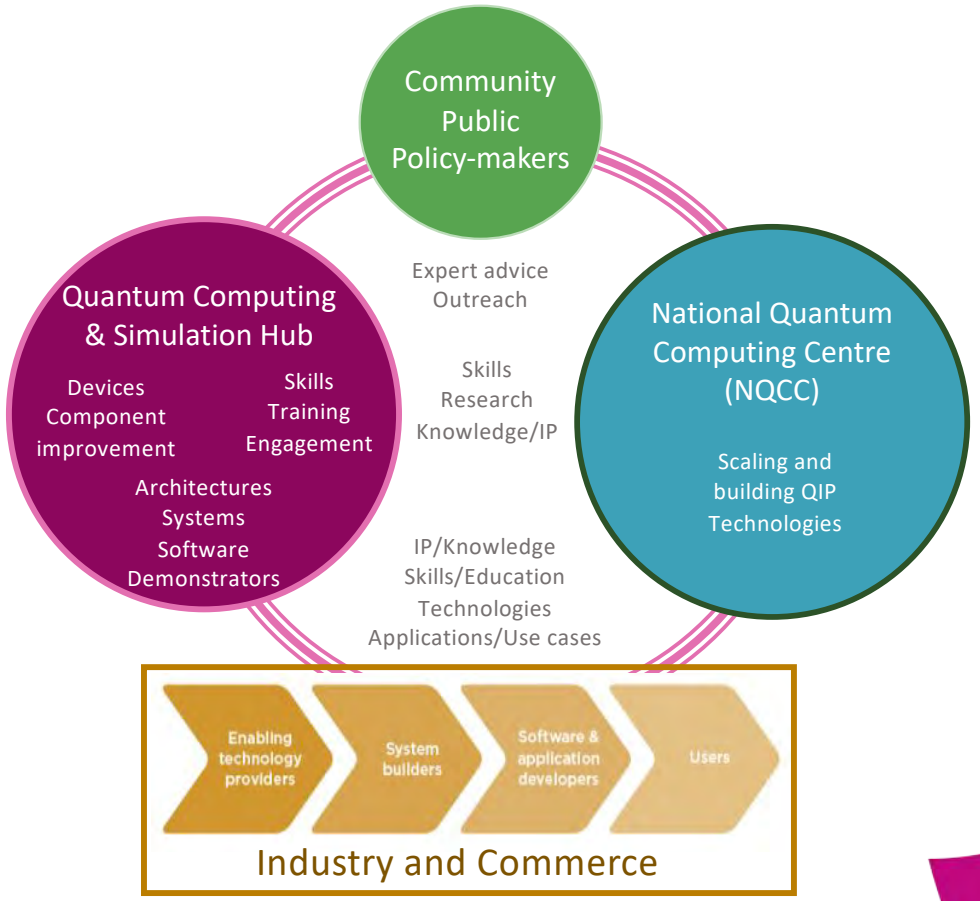
QCS Hub Context

- The Hub creates the building blocks for the NQCC and industry to scale and exploit
- Industry Engagement with all parts of the value chain: enabling technologies, system integrators, application developers and users
- Partnerships with IBM, Google a.o.
- Encouraging quantum readiness (QRP) and quantum literacy in industry and with the public
- Encourage quantum literacy through outreach (Quantum City)
- Support all parts of the UK National Quantum Technologies Programme: Technology Hubs, Skills Hubs, Innovate UK ISCF, KTN Quantum SiG, NPL, The National Quantum Computing Centre, policy makers and sponsors including Dstl and NCSC



How the QCS Hub can help

We collaborate with suppliers, integrators and developers, prospective users, entrepreneurs and investors, and regulators:

- Partnership Resource Funding for collaborative projects
- Publish Reports and run a Quantum Readiness Programme
- Partnerships with system vendors, e.g. IBM Quantum
- Access to the research community
- Public outreach through Quantum City, a UKNQTP collaboration

To get involved, please contact the engagement team at qcshub.org

Quantum Computing & Simulation Hub

User Engagement – Mission

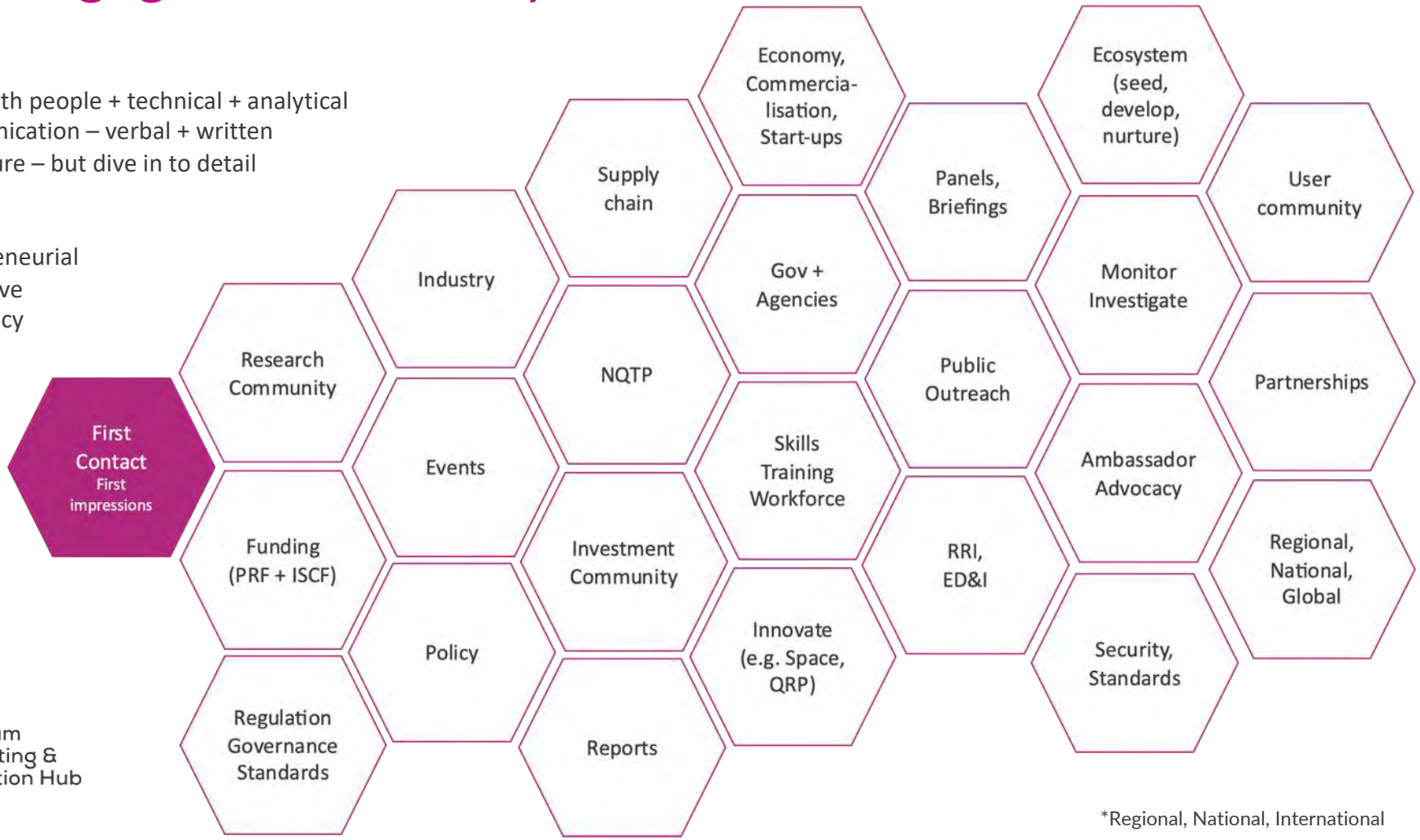
> Develop and nurture the quantum computing ecosystem for UK prosperity

Quantum Computing & Simulation Hub

User Engagement – Ecosystem*

Skills:

- Good with people + technical + analytical
- Communication – verbal + written
- Big picture – but dive in to detail
- Curious
- Flexible
- Entrepreneurial
- Innovative
- Diplomacy



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*Regional, National, International

For BCS Berkshire Members

The UK Quantum Industry Landscape*

(For illustration only, no relationships implied)

Hardware

OQC

ORCA Computing

OXFORD IONICS

QUANTUM MOTION

Universal Quantum

Software

CQC Cambridge Quantum Computing

PHASECRAFT

rahko

river lane

Security

Crypta Labs

KETS

QD Quantum Dice

nu QUANTUM

PQSHIELD

Systems

Atos

Google AI

IBM Q

rigetti

Users

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Trakm8 Data driven insights

AIRBUS

JM Johnson Matthey Inspiring science, enhancing life

Standard Chartered

BARCLAYS

BT

* Not a detailed list

Publicly announced developments

Hardware

- £10m project led by Rigetti UK to build quantum computer based on superconducting circuits
- Consortium includes: Oxford Instruments, University of Edinburgh, Phasecraft, and Standard Chartered Bank.

Oxford Instruments: ProteoxLX dilution refrigerator
(Base temperature as low as 7mK)

Rigetti quantum processor

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Publicly announced developments

Software

- £7.6m project led by Riverlane to build ***DeltaFlow.OS*** – a quantum computing operating system
- Consortium includes: SeeQC, Hitachi Europe, Universal Quantum, Duality Quantum Photonics, Oxford Ionics, Oxford Quantum Circuits, Arm and the National Physical Laboratory.

Publicly announced developments

Commercial

IonQ IPO US $2bn!

HPCwire

Since 1987 - Covering the Fastest Computers in the World and the People Who Run Them

- Home
- Technologies
- Sectors
- COVID-19
- AI/ML/DL
- Exascale
- Specials
- Resource Library
- Podcast
- Events
- Job Bank

Quantum Computer Start-up IonQ Plans IPO via SPAC

By John Russell

March 8, 2021

IonQ, a Maryland-based quantum computing start-up working with ion trap technology, plans to go public via a Special Purpose Acquisition Company (SPAC) merger according to a report in today's Wall Street Journal. The deal would value IonQ at $2 billion and make it the first pure-play quantum computing company to go public.

SPACs aren't new but have recently become more popular. In this deal IonQ would merge with the 'blank check' firm dMY Technology Group. Here's a quick description of the SPAC methodology from Investopedia:

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The Technological Landscape

We’re not starting from the same roots as classical computing!!

- Quantum computers – emerging
- Cloud – democratise access to quantum computers
- Powerful classical computers
- Machine learning
- Neuromorphic computing

Threats or opportunities?

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"How do you bridge the Quantum Divide?"

The Education Landscape

How old do you need to be to learn quantum computing?

- Qubit by Qubit
  - 10,000 students across 125 countries
  - Middle School, High School and above!
- Q-Munity
  - Started by a 14 year old
  - Taught herself quantum computing and created an algorithm to detect Parkinson's using speech data
- Many online courses and tutorials – but can you be hired?

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How to engage with quantum computing

- Talk to us! – https://www.qcshub.org
- Qiskit – open source https://qiskit.org/
- IBM Quantum – https://www.ibm.com/quantum-computing/
- Quantum Apalooza – https://quantumapalooza.com/
- Quantum Algortihms – https://quantumalgorithmzoo.org/

- Lots of books too!

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Thank you!

Find us at qcshub.org

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