Accelerating quantum technologies through measurements & standards

A readout from the BIPM workshop and an introduction to NMI-Q

JT Janssen Chair

NMI-Q Steering Committee: Davide Calonico, Barbara Goldstein, Jan Herrmann, Nobu-Hisa Kaneko, Tim Prior, Nicolas Spethmann, Kevin Thomson

23rd meeting of NMI Directors and Member State Representatives

17-18 October 2024

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The quantum technology ecosystem in 2023

Summary of Quantum Technology Monitor findings

$106B

potential quantum technology market size by 2040[1]

350

start-ups in the ecosystem[2]

Quantum computing

$9B–$93B

estimated market size by 2040

$5.4B
invested as of Dec 2022

223
start-ups as of Dec 2022

Quantum communications

$1B–$7B

estimated market size by 2040

$1.0B
invested as of Dec 2022

72
start-ups as of Dec 2022

Quantum sensing

$1B–$6B

estimated market size by 2040

$0.4B
invested as of Dec 2022

23
start-ups as of Dec 2022

$34B total government investment announced

Potential economic value from quantum computing

$620B–$1,270B

across four industries by 2035: chemicals, life sciences, finance, and automotive[3]

Quantum-capable talent

50
QT master's degree programs

180
universities with QT research groups

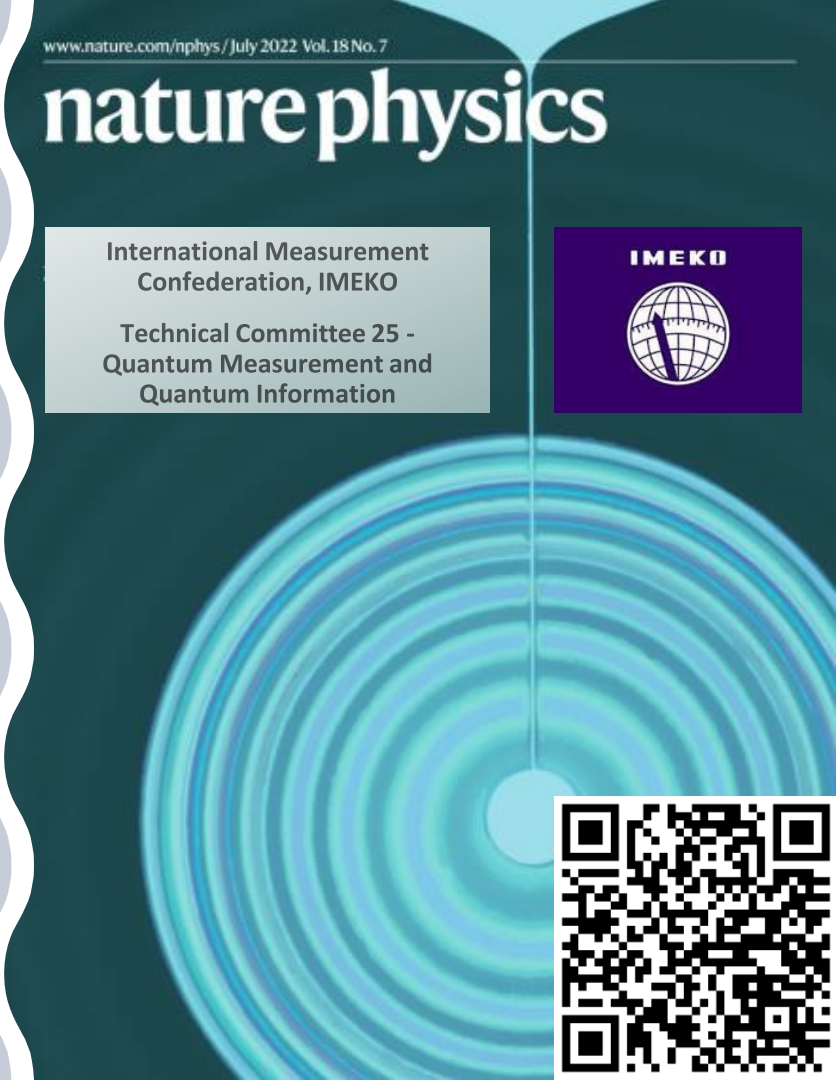
Scientific progress

1,589
QT-related patents granted in 2022

44,155
QT-related publications in 2022

The Expanding Role of National Metrology Institutes in the Quantum Era

Alexander Tzalenchuk, Nicolas Spethmann, Tim Prior, Jay H. Hendricks, Yijie Pan, Vladimir Bubanja, Guilherme P. Temporão, Dai-Hyuk Yu, Damir Ilić and Barbara L. Goldstein



Emerging technologies demand innovations in metrology

Agility: to keep up with rapidly changing technical landscape

Ability: to make a measurement at all (traceability may lag if needed at all)

Comparability: across vendors, quickly, continuously

Accelerated delivery: Formal standards may be obsolete by the time they're published

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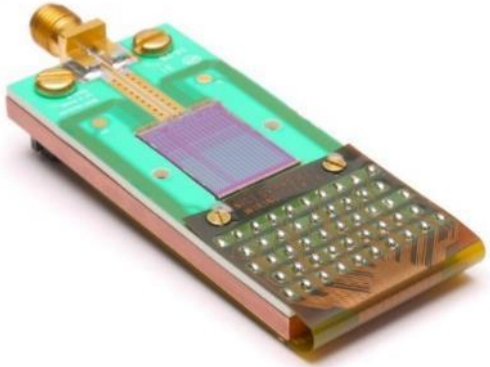
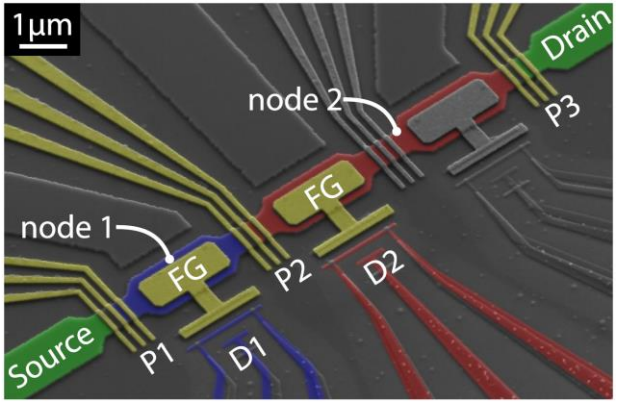
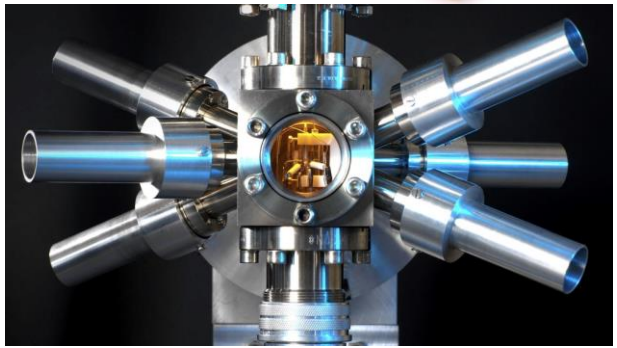
NMIs

- first to develop
- first to benefit







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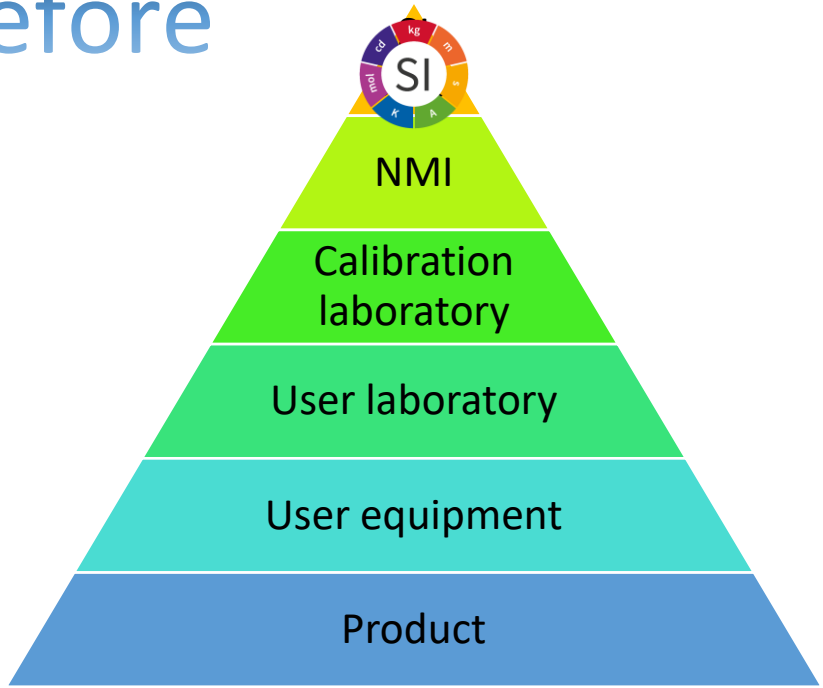
Discoveries and applications in metrology

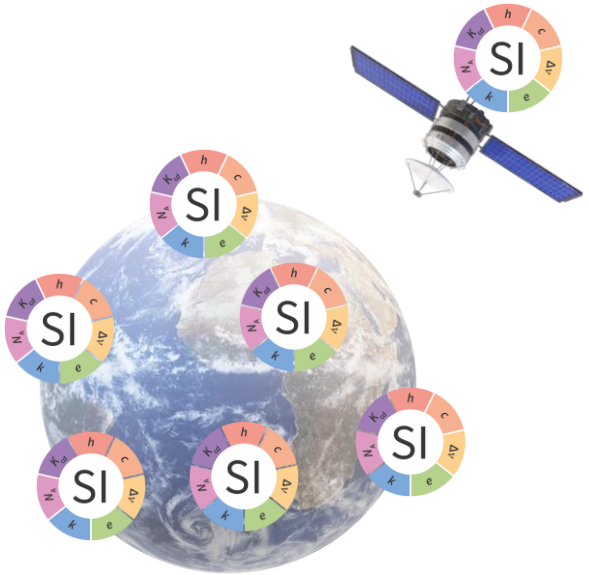
- Time metrology. Masers and atomic clocks. [**1944 -** Isidor Isaac Rabi , **1964 -** Charles H. Townes, Nicolay G. Basov, Aleksandr M. Prokhorov]
- Frequency standards. Ion traps, laser cooling. BEC. [**1989 -** Norman F. Ramsey, Hans G. Dehmelt, Wolfgang Paul, **1997 -** Steven Chu, Claude Cohen-Tannoudji, William D. Phillips, **2001 -** Eric A. Cornell, Wolfgang Ketterle, Carl E. Wieman]
- Lasers, interferometry and spectroscopy, frequency combing [**1907** - Albert Michelson, **2005 -** Roy J. Glauber, John L. Hall, Theodor W. Hänsch]
- Dimensional and functional metrology on the nano-scale. Scanning probe microscopy [**1986 -** Ernst Ruska, Gerd Binnig, Heinrich Rohrer]
- The Josephson effect and the volt [**1973 -** Leo Esaki, Ivar Giaever, Brian D. Josephson]
- Quantum Hall effect and the ohm [**1985 -** Klaus von Klitzing]
- Graphene [with the first application in resistance standard **2010 -** Andre Geim & Konstantin Novoselov]
- Quantum control and clocks [**2012 –** Serge Haroche & David Wineland]

Democratised traceability

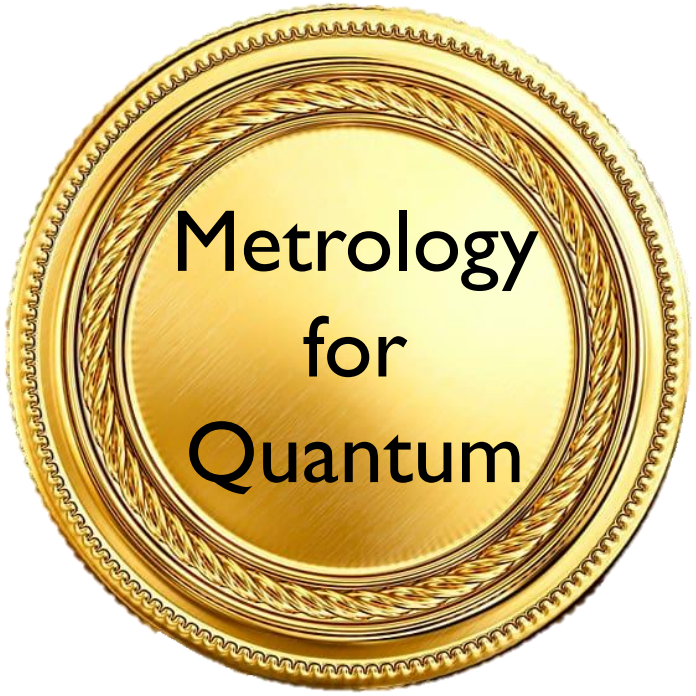
Before



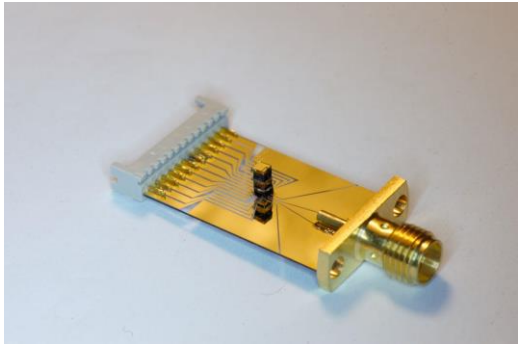
Now

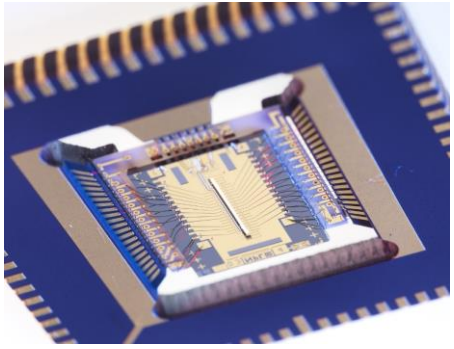


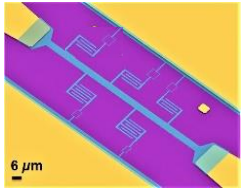
Question:
Who owns traceability?



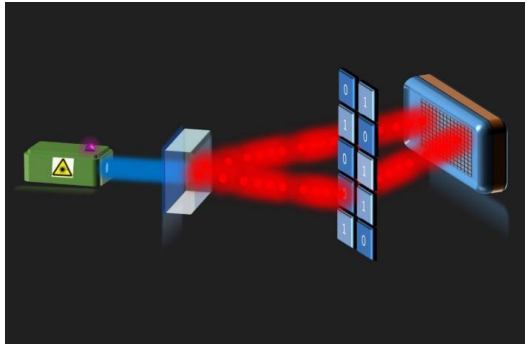
What does industry need from us to develop quantum technologies?







Quantum Integrated Circuits



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Department for Science, Innovation & Technology

UK Real world applications and products

Wearable brain scanner with better sensitivity and lower cost

cerca Magnetics Limited | The University of Nottingham

Putting quantum technologies in space to secure future communications

INNOVATIVE | UNIVERSITY of York

Measuring emissions and greenhouse gases more accurately than ever before

QLM Enabling Net Zero | University of BRISTOL

First commercial trial of a quantum secured communications network in the world

Bureau ition s et Mesures | BT | TOSHIBA | UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME

Gravity gradient sensor 'seeing' the invisible underground

RSK | UNIVERSITY OF BIRMINGHAM

Workshop Steering Committee

CIPM (JT Janssen)
BIPM Secretary (Pierre Gournay)

NRC-Canada (Kevin Thomson)
NPL-UK (Tim Prior)
NIST-US (Barbara Goldstein)
NMIJ-Japan (Nobu-Hisa Kaneko)
NMIA-Australia (Jan Herrmann)
PTB-Germany (Nicolas Spethmann)
INRiM-Italy (Davide Calonico)

- **149 participants** from 43 NMIs and DIs from 39 economies, and industry associations worldwide
- Consensus to collaborate on quantum technology **pre-standardization**
- Workshop report: **https://www.bipm.org/en/bipm-workshops/quantum-tech**
- NEXT STEPS: Steering committee to produce **White Paper** with recommendations

Workshop conclusions

There is a **clear industry need** for application-relevant measurements and standards to advance quantum technologies, and a sense of urgency to address those needs.

- Such standardisation efforts require collaboration – no organisation / country can do it alone.

NMIs are uniquely positioned to contribute to, facilitate and drive those efforts:

- Track record both in early adoption of quantum technologies ('**quantum for metrology**') and in supporting the development of quantum science and technology ('**metrology for quantum**').
- Recognised as **independent**, with an established **culture of collaboration**

Given the critical role of metrology in the emerging quantum industry, there is a **need for a suitable structure / organisation** to coordinate collaboration between NMIs, aligned with CIPM/BIPM.

Workshop conclusions

BIPM/CIPM has a clear mandate to lead SI unit-based metrology, which includes quantum technology for metrology.

The emerging quantum industry requires measurements, developed in a commercially relevant timeframe, which requires further development of the SI.

A new organisation can address this metrology-for-quantum gap by leveraging the expertise of NMIs and DIs, and working closely with BIPM, industry bodies and standards development organisations.

BIPM/CIPM
Quantum Technology for Metrology

NMIs
Metrology for Quantum Technology Standards

Steering Committee recommendation

nmi^{Q}

Establish a quantum focused, NMI-led, organisation to promote global innovation and adoption of quantum technologies through international collaborations that provide the technical basis for harmonisation of measurement methods, leading to best practices and standards - **nmi^{Q}**

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Benefits of nmi^{Q}

nmi^{Q}

Rapidly develop industry-relevant measurements by metrology experts

Establish technical basis for future national and international standards for quantum technologies through:

- Pre-normative R&D in rapidly developing technical areas
- Collaborative development of best practices, test methods and procedures
- Transferring results to standards bodies

Build capabilities and increase the quantum proficiency of NMIs and other laboratories through:

- Providing opportunities for multi-NMI collaboration
- Contributing to BIPM programmes and support for knowledge transfer and training

Governance

nmi^{Q}

Steering committee members currently developing the final model for **nmi^{Q}**

- Model will be similar to VAMAS

Participation

Aim to open application process for membership by April 2025

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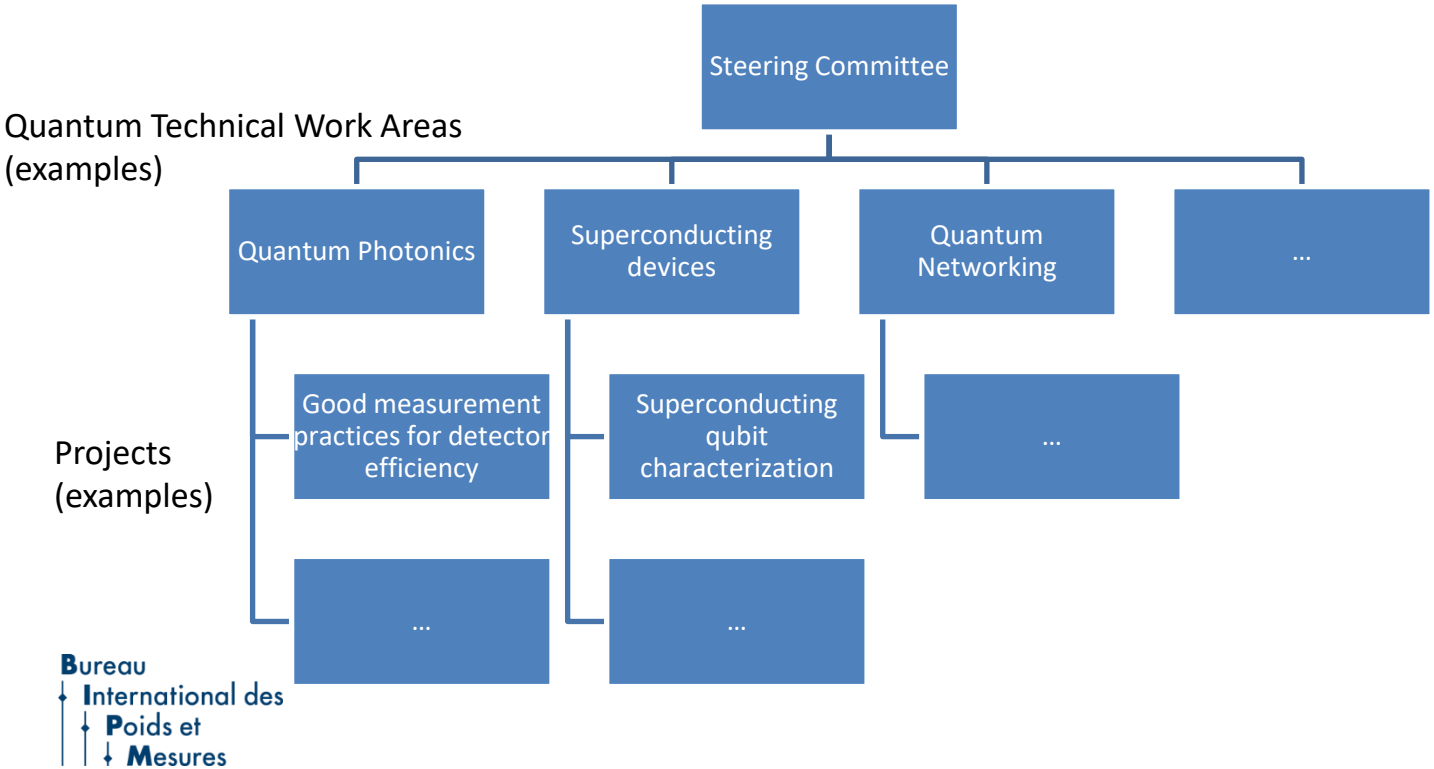
Preliminary organizational structure

nmi^{Q}



Connections

nmi^{Q}

Bureau International des Poids et Mesures (BIPM)

Collaboration on identification of key metrological traceability issues affecting the comparability and accuracy of measurements for quantum technologies. Joint events, workshops, publication, dissemination, educational outreach and knowledge transfer.

ISO and IEC

Joint publications based upon the work of **nmi^{Q}** to provide the technical basis for future standards for quantum technologies.

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Thank you

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