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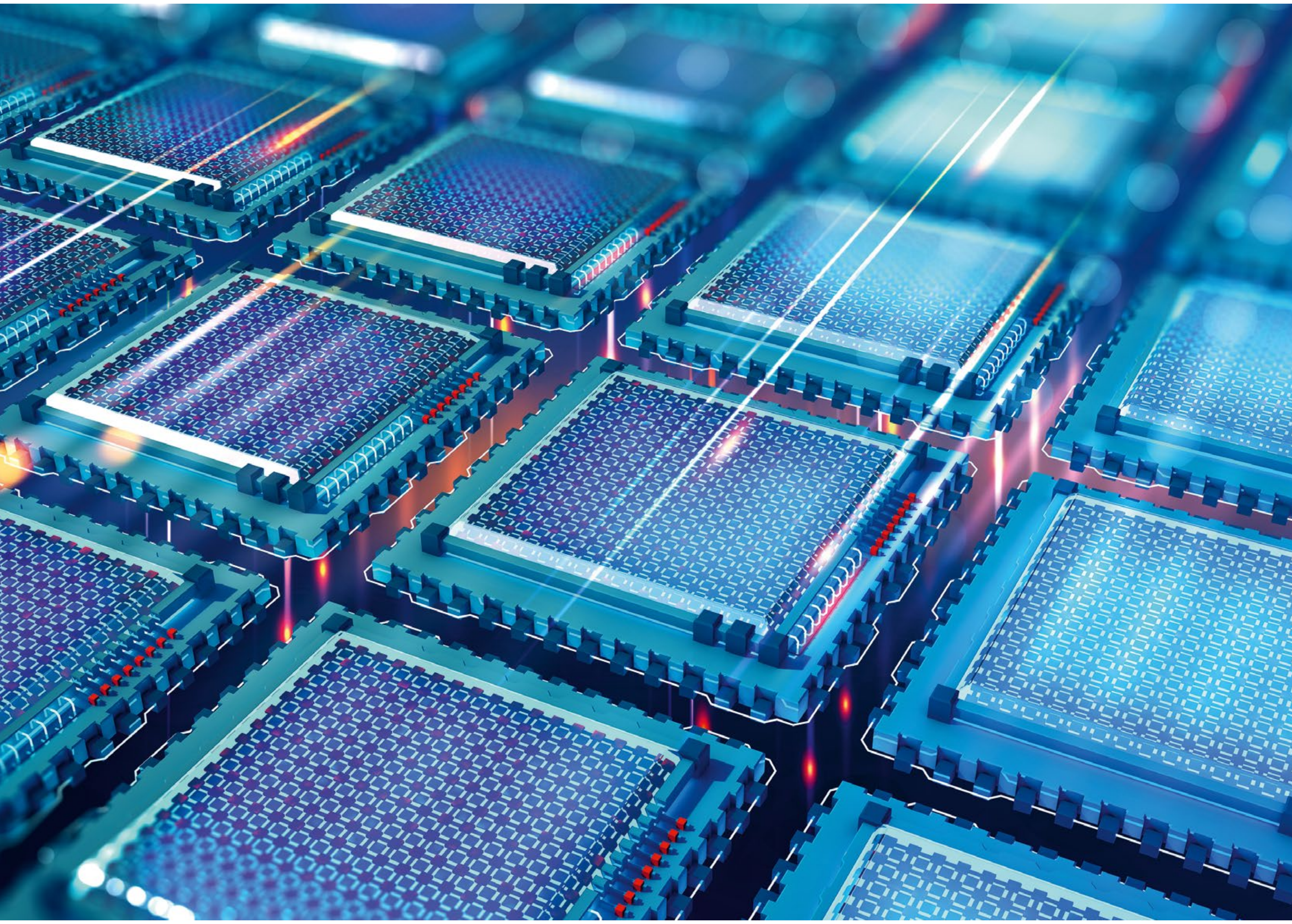

European Competence Framework for Quantum Technologies

compiled by Franziska Greinert and Rainer Müller,
supported by Simon Goorney, Riccardo Laurenza,
Jacob Sherson and Malte Ubben

Version 2.0 (April 2023)

European Competence Framework for Quantum Technologies Overview – Version 2.0

Quantum background

1 CONCEPTS AND FOUNDATIONS

- 1.1 Basic quantum concepts
- 1.2 Mathematical formalism and information theory

2 PHYSICAL FOUNDATIONS OF QUANTUM TECHNOLOGIES

- 2.1 Atomic physics
- 2.2 Quantum optics and electrodynamics
- 2.3 Solid-state physic
- 2.4 Quantum many-body systems and open quantum systems

Core device technologies

3 ENABLING TECHNOLOGIES AND TECHNIQUES

- 3.1 Laboratory techniques, noise and shielding
- 3.2 Solid-state technologies, nanotechnologies
- 3.3 Optical technologies
- 3.4 Control technologies
- 3.5 Computers and software

4 QUANTUM HARDWARE

- 4.1 Superconducting electronic circuits
- 4.2 Spin-based systems
- 4.3 Neutral atoms and ions
- 4.4 Photonic systems
- 4.5 Emerging qubit concepts
- 4.6 Quantum state control
- 4.7 Hybrid quantum-classical systems
- 4.8 Technology realisation

QT systems and applications

5 QUANTUM COMPUTING AND SIMULATION

- 5.1 Basics
- 5.2 Quantum simulators
- 5.3 Quantum programming tools and software stack, error correction
- 5.4 Quantum computing subroutines
- 5.5 Quantum algorithms
- 5.6 Applications of quantum computing and simulation

7 QUANTUM COMMUNICATION AND NETWORKS

- 7.1 Basics
- 7.2 Quantum random number generators
- 7.3 Quantum key distribution
- 7.4 Applications of quantum cryptography
- 7.5 Infrastructure for quantum information networks (quantum internet)
- 7.6 Systems networks (composite systems), quantum internet applications

6 QUANTUM SENSORS AND IMAGING SYSTEMS

- 6.1 Basics
- 6.2 Electromagnetic field sensors
- 6.3 Temperature, particle and pressure sensors
- 6.4 Inertial and gravity sensors
- 6.5 Quantum imaging
- 6.6 Atomic clocks
- 6.7 Applications of quantum sensors

8 VALORISATION

- 8.1 Industry landscape and market analysis
- 8.2 Business strategy, entrepreneurship and management
- 8.3 Impact
- 8.4 Responsibility and awareness

Version 2.0 (April 2023) compiled by Franziska Greinert and Rainer Müller, supported by Simon Goorney, Riccardo Laurenza, Jacob Sherson and Malte Ubben
QUCATS – Quantum Flagship Coordination AcTion and Support
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How to use the Competence Framework

The European Competence Framework for Quantum Technologies aims to map the landscape of possible knowledge and skills in Quantum Technologies. It has been compiled in the Quantum Flagship CSAs (QTEdu, QUCATS) in order to facilitate the planning and design of education and training projects in Quantum Technologies.

The Competence Framework consists of eight **domains**. They outline the broad structure of Quantum Technologies:

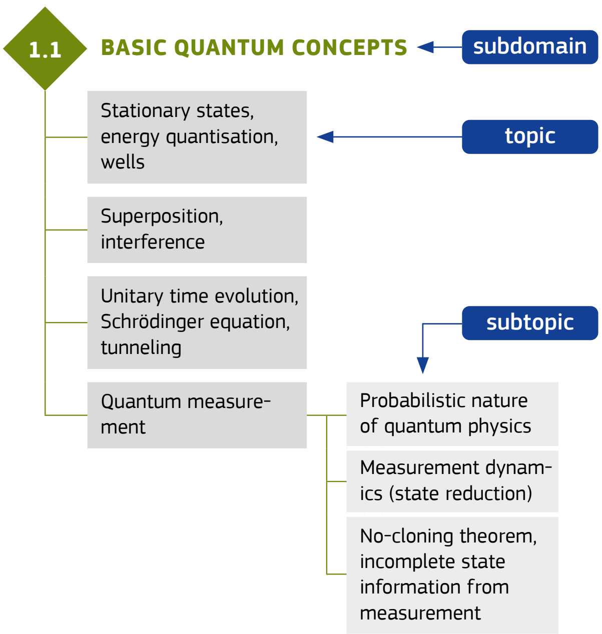
1 CONCEPTS AND FOUNDATIONS

Each of these eight domains has several subdomains, e. g.

1.1 BASIC QUANTUM CONCEPTS

1.2 MATHEMATICAL FORMALISM AND INFORMATION THEORY

On the first page of this document, the overview of the **domains** and **subdomains** is shown in a graphical scheme. For each domain there is an extra page with more details:



Depending on the target audience, each educational offer will address different levels of depth and difficulty. To reflect this, there is an additional dimension to the Competence Framework that is not shown in the overview graphic. For each entry, a proficiency level can be specified: from A1 (Awareness) to C2 (Innovation). The use of **proficiency levels** makes it easier to tailor education and training offers to the needs of the target groups. New in version 2.0 are extended descriptions of these levels adapting the European Qualification Framework levels, see p. 5.

A1	**Awareness**	**A2**	**Exploration**
B1	**Adaptation**	**B2**	**Expertise**
C1	**Specialisation**	**C2**	**Innovation**

In addition, the new p. 4 explains the overall structure by describing the three larger blocks of two or four domains, supplemented by key skills for the blocks.

The Competence Framework has been compiled using a bottom- up approach. Between summer 2020 and spring 2021, a three- round study with over 150 participants from the QT community provided initial input (see paper *The Future Quantum Workforce: Competences, Requirements and Forecasts*, to be published in Phys. Rev. Phys. Educ. Res., preprint on doi: arXiv:2208.08249). The results were refined through expert interviews for each domain, leading to version 1.0 from May 2021. Details are documented in the *Methodology and Version History* (2021, doi: 10.2759/130432). For the current version 2.0, feedback and usage experiences have been incorporated, and events have been conducted to involve the community.

Quantum Technologies are rapidly evolving. New technologies will be developed, others will become less important. The Competence Framework will have to be adapted accordingly. Thus, the Competence Framework is a living document that will be updated in regular intervals. Suggestions for additions and corrections are welcome at any time.

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Overall structure:
Three blocks with descriptions and key skills

New in Version 2.0

Quantum background

Quantum background

The quantum background covers the basic concepts (subdomain 1.1) that are relevant for the phenomenological understanding ("awareness") of the basic idea of quantum technologies, their advances and challenges compared to classical technologies. Subdomain 1.1 also covers advanced concepts that form the common basis for the quantum physical foundations (domain 2). Similarly, subdomain 1.2 covers both basic mathematical concepts and higher mathematics for domain 2 that are relevant for describing the concepts and functionality of QT or for computing or predicting applications as well as information theory foundations. The physical foundations are divided into four subdomains in which one could specialise, including theories and effects, strategies and key experiments.

Key skills

Communicate/explain: Ability to explain concepts, phenomena, etc. and to communicate about quantum.
Mathematics: Describe quantum phenomena/concepts and underlying physics with mathematics and use mathematics to calculate/compute and predict applications.
Theoretical physics: Understand or develop new approaches, identify potential for advances.
Experiments: Plan and prepare experiments, conduct experiments and document and evaluate results.

Background

Core device technologies

Core device technologies

This block covers the technical foundations for building a complete quantum technology system. The core of these systems, the different hardware platforms for the use of individual quantum objects (subdomains 4.1 to 4.5) and the direct control of these physical qubits (4.6) are located in the quantum hardware (domain 4). The enabling technologies, i.e. the components around the quantum core to build the complete QT system and the related techniques are covered in domain 3, including software development (3.5) to control the hardware. In addition, the integration into hybrid systems (4.7) and the technological realisation (4.8) are covered.

Key skills

Manufacturing: Technical/mechanical skills to build/assemble hardware.
Hardware: Laboratory techniques (lab skills), component or system improvement, testing and maintenance.
Software: Coding/programming (classical), data processing and analysis, interpretation.
Technology realisation: Requirements definition, planning, integration of quantum hardware platforms with control technologies, software, etc. into QT systems.

From component to application

QT systems and applications

QT systems and applications

These domains cover the range of full quantum technology (QT) systems and their applications. Each of the three main QT pillars has a dedicated domain, namely q. computing and simulation (domain 5), q. sensors and imaging systems (6) and q. communication and networks (7). Each of these domains starts with domain-specific foundations (5.1, 6.1, 7.1), followed by devices or processes such as key distribution or quantum programming. They end with application areas and example use cases (5.6, 6.7, 7.4 and 7.6). Domain 7 has a special two-part structure, with 7.2 to 7.4 on quantum cryptography and 7.5 and 7.6 on quantum networks. In addition, domain 8 covers the general business perspective, with impact and landscape, as well as addressing responsibility and awareness raising.

Key skills

Use: Operate a device or run an algorithm and analyse/interpret data in context of the use case.
Identify use cases, create value: Identify potential use cases, analyse advantages and possibilities to create industrial value.
Translate use cases: Translate real-world use case into application requirements.
Adaptation/implementation: Compare and choose from different approaches, adapt or combine these depending on the use case.

Supply chain

Component supplier → Development → Systems assembly → Selection, consultancy → Adaptation → End-user

Proficiency levels with examples

New in Version 2.0

A1 **Awareness** *(a few hours)*
Basic idea, overview of possibilities and limitations, reproduce solutions, operate a device or run an algorithm.

A2 **Exploration** *(a few days)*
Knowledge of fundamentals or landscape of approaches, describe functionalities, read and interpret an algorithm or a description.

B1 **Adaptation** *(few weeks course)*
Specialised knowledge in a subdomain, awareness of its boundaries, explain complex functionalities, adapt approaches for concrete settings.

B2 **Expertise** *(short research project)*
Advanced knowledge, critical perspectives, assessment of consequences, adapt or develop solutions for real-world use cases, identify possible use cases.

C1 **Specialisation** *(longer research project)*
Highly specialised knowledge, critical awareness of interconnections, new solutions and methods, combine and integrate approaches.

C2 **Innovation** *(long-year experience with R&D)*
Most advanced knowledge, interconnections, develop innovative solutions, evaluate and assess, extend and redefine professional practice.

Proficiency levels (general descriptions, long format)
with K: Knowledge, S: Skills (ability to do something)

A1 Awareness *(up to a few hours of instruction or self-study)*
K: Basic idea (phenomena-oriented) of related concepts and functionalities, know basic vocabulary, overview of possibilities, challenges and limitations.
S: Ability to reproduce solutions for small problems, operate a device or run an algorithm after instruction.

A2 Exploration *(up to a few days of instruction or self-study)*
K: Knowledge of fundamental formalism and (working) principles, or landscape of approaches/products/use cases.
S: Ability to describe functionalities with physical and mathematical concepts, read and interpret an algorithm or process description, identify which approach to use in which situation.

B1 Adaptation *(e.g. through a semester-long lecture with practical tasks, homework and/or laboratory course; a few weeks of summer school)*
K: Knowledge of a variety of approaches, specialised knowledge in a selected subdomain, awareness of the boundaries of this knowledge.
S: Ability to explain complex functionalities, adapt approaches for concrete settings.

B2 Expertise *(e.g. through a short research project as for a bachelor thesis, internship with project)*
K: Advanced knowledge of theories, approaches and methods and their validity, including critical perspectives, and assessment of consequences.
S: Ability to adapt or develop solutions for complex and unpredictable problems and for real-world use cases with state-of-the-art technologies, identify possible use cases and advances.

C1 Specialisation *(e.g. through a longer research project such as for a Master's thesis, a longer internship or work experience with an R&D project)*
K: Highly specialised knowledge in one subdomain and critical awareness of interconnections between different (sub-)domains.
S: Ability to find or develop innovative solutions for new problems or use cases, generate new methods, combine and integrate approaches and solutions from different (sub-)domains.

C2 Innovation *(e.g. through a long research project such as a PhD thesis, long-term work experience in an R&D project)*
K: Most advanced knowledge in the subdomain and on interconnections with different approaches and (sub-)domains.
S: Ability to find or develop innovative solutions for critical problems or use cases, evaluate and assess solutions, extend and redefine knowledge or professional practice.

Examples for proficiency levels
with K: Knowledge, S: Skills (ability to do something)

A1 Awareness *in concepts and foundations (1)*
K: Basic idea (phenomena-oriented) of the fundamental quantum concepts and vocabulary such as superposition and entanglement, challenges in measurement and through decoherence, and basic mathematical notation of quantum states.
S: Ability to explain the basic idea of a QT and its potential.

A2 Exploration *in quantum computing (5)*
K: Knowledge of qubit concepts and corresponding formalism (5.1), overview of the algorithm landscape (5.5).
S: Ability to read and interpret an algorithm (5.3), identify which computational approach (5.5) may bring advantage for which use case (5.6).

B1 Adaptation *in quantum sensing: gravity (6.4)*
K: Knowledge of a variety of quantum sensing devices (6.2–6.6), specialised knowledge about quantum gravity sensors (6.4) with current and potential use cases and challenges (from 6.7).
S: Ability to adapt a sensing device to a concrete use case, such as mapping archaeological structures (6.7.c).

B2 Expertise *in quantum communication: QKD (7.3)*
K: Advanced knowledge of QKD protocols (7.3), including critical perspectives and assessment of approaches, e.g. regarding security proofs and consequences for implementation.
S: Ability to adapt a QKD setup for a new use case, e.g. for a voting procedure and associated data transmission, select the state-of-the-art technologies to be used; identify potential new use cases where this approach can also bring advantages.

C1 Specialisation *in enabling technologies: optical technologies (3.3)*
K: Highly specialised knowledge in the field of optical technologies (3.3) and critical awareness of interconnections with other technology fields like solid-state technologies (3.2) and control technologies (3.4).
S: Ability to develop innovative hardware systems combining components and control hardware, generate new methods to integrate optical components with other hardware components.

C2 Innovation *in quantum hardware: superconducting circuits (7.1)*
K: Most advanced knowledge on superconducting electronic circuits (4.1) and their use as qubits for quantum computing in combination with qubit control (4.6) and other technologies (3), including challenges and steps towards technology realisation (4.8).
S: Ability to develop innovative solutions for scalable and fault-tolerant qubits, evaluate and assess different approaches, extend and redefine professional practice with new and successful solutions.

References:
Proficiency level system: Level A1 to C2 like in the *Common European Framework of Reference for Languages* (CEFR, 2020, 2001, www.coe.int/lang-cefr), which has been used in the *European Framework for the Digital Competence of Educators* (DigCompEdu, 2017, doi: 10.2760/159770), the template for the framework structure and level keywords. Proficiency level descriptions are based on the levels from *The European Qualifications Framework* (EQF, 2018. doi: 10.2767/750617).

1 CONCEPTS AND FOUNDATIONS

1.1 BASIC QUANTUM CONCEPTS

- Stationary states, energy quantisation, wells
- Superposition, interference
- Unitary time evolution, Schrödinger equation, tunneling
- Quantum measurement
  - Probabilistic nature of quantum physics
  - Measurement dynamics (state reduction)
  - No-cloning theorem, incomplete state information from measurement
- Two-state systems (e. g. spin-1/2, polarisation), qubits
  - State representation, visualisation (e. g. Bloch/Poincaré sphere)
  - Dynamics of two-state systems
  - Physical manipulation with pulses
  - State evolution, Bloch equation, Larmor precession, Rabi oscillations
- Pure and mixed quantum states
- Decoherence and coupling to the environment
- Heisenberg principle, complementarity
- Entanglement, Bell inequalities, non-locality

1.2 MATHEMATICAL FORMALISM AND INFORMATION THEORY

- Mathematical foundations
  - Linear algebra, functional analysis
  - (Linear) differential equations
  - Statistics, probability theory, combinatorics
  - Advanced mathematics, e. g. topology, group theory, symmetry
  - Perturbation theory
- State space, Dirac notation
- Operators, eigenvectors, eigenvalues
- Classical information theory, Shannon entropy
- Quantum channels, distance measures, von Neumann entropy

2 PHYSICAL FOUNDATIONS OF QUANTUM TECHNOLOGIES

2.1 ATOMIC PHYSICS

- Electronic levels, quantum numbers, level transitions, Rydberg states
- Hyperfine structure, Zeeman effect, Stark effect
- Angular momentum (spin, orbital, total), interactions

2.2 QUANTUM OPTICS AND ELECTRODYNAMICS

- Classical, quantum and non-linear optics, polarisation degrees of freedom
- Photon statistics, bunching, antibunching
- Fock states, coherent states, squeezed states
- Quantum optical experiments, interferometry, microscopy and spectroscopy
- Quantum electrodynamics (QED)
- Light-matter interactions

2.3 SOLID-STATE PHYSICS

- Properties (band structure, electrical transport, optical properties, magnetism)
- Semiconductor theory
- Superconductivity, Josephson effect, Josephson junctions
- Mesoscopic phenomena, quantum confinement effects
- Topological effects
- Magnetometry, spin manipulation experiments

2.4 QUANTUM MANY-BODY SYSTEMS AND OPEN QUANTUM SYSTEMS

- Pauli principle, bosons, fermions, Fermi gases and Fermi liquids
- Quantum degenerate gases, Bose-Einstein condensation
- Quantum statistics, entropy
- Molecular physics
- Open quantum systems
- Decoherence mechanisms (relaxation, dephasing, photon loss)

3 ENABLING TECHNOLOGIES AND TECHNIQUES

3.1 LABORATORY TECHNIQUES, NOISE AND SHIELDING

- Noise analysis
- Cryogenic, vacuum and cleanroom technologies
- Shielding techniques, housing, magnets

3.2 SOLID-STATE TECHNOLOGIES, NANOTECHNOLOGIES

- Micro- and nanostructuring
- Quantum materials design
- Micro- and nanoelectronics, e. g. 2D electron gas and materials, single-electron transistor (SET), spintronics
- Semiconductor technologies
- Superconducting devices, SQUIDs

3.3 OPTICAL TECHNOLOGIES

- Classical optics
- Lasers
- Single photon sources
- Single photon detectors and cameras
- Photonics, fibres

3.4 CONTROL TECHNOLOGIES

- Signal and data processing
- Electronics, microwave and RF (radio frequency) technologies, frequency conversion, modulation and generation
- Laser cooling, laser stabilisation
- Generation of special quantum states, e. g. Bell states, squeezed states
- Resonators
- Opto-electronical and opto-mechanical systems

3.5 COMPUTERS AND SOFTWARE

- IT infrastructure and software stack
- Classical programming, algorithm design and software development techniques, mathematical modelling
- Control software: calibration, guide electronics/ optics, error-robust physical operations, tuning and stabilisation of hardware
- Quantum control algorithms
- Machine learning inspired and integrated approaches

4 QUANTUM HARDWARE

4.1 SUPERCONDUCTING ELECTRONIC CIRCUITS

- Qubit types, e. g. charge, flux, phase, transmon

4.2 SPIN-BASED SYSTEMS

- Electron-spin qubits, nitrogen-vacancy (NV) centres in diamond
- Semiconductor quantum dots
- Nuclear-spin qubits

4.3 NEUTRAL ATOMS AND IONS

- Trapped ions
- Rydberg atoms
- Cold atoms, molecules, quantum gases
- Neutral atoms in optical lattices

4.4 PHOTONIC SYSTEMS

- Linear optical elements and networks, optical instruments for photons as qubits
- Boson sampling techniques
- Entangled photon sources

4.5 EMERGING QUBIT CONCEPTS

- Topological qubits
- Molecular-spin qubits

4.6 QUANTUM STATE CONTROL

- State initialisation and readout
- State manipulation, realisation of quantum gates
- Qubit coupling & interconnectivity
- Interconversion of different qubit types

4.7 HYBRID QUANTUM SYSTEMS

- High performance computer (HPC) systems
- Machine learning integration
- Integration of classical and quantum networks
- Quantum interfaces

4.8 TECHNOLOGY REALISATION

- Noise, general and platform-specific limitations, benchmarking
- Miniaturisation, scaling
- Integration on a chip, e. g. photonic integrated circuits, atom chips

5 QUANTUM COMPUTING AND SIMULATION

5.1 BASICS

- Reversibility, DiVincenzo criteria
- Qubits, quantum gates, universal gate set
- Universal fault-tolerant quantum computers, NISQ quantum computers
- Circuit design, notation, matrix representation
- Basic quantum programming techniques
- Complexity theory, quantum complexity classes, computational limitations, quantum advantage

5.2 QUANTUM SIMULATORS

- Digital quantum simulators
- Analogue quantum simulators and (adiabatic) quantum annealers

5.3 QUANTUM PROGRAMMING TOOLS AND SOFTWARE STACK, ERROR CORRECTION

- Graphical platforms
- Quantum assembler languages and software development kits, quantum circuit simulators
- Quantum compilers, high-level programming with pre-definded subroutines
- Hybrid quantum-classical algorithms and quantum embedding
- Cloud platforms
- Quantum error correction, quantum error mitigation

5.4 QUANTUM COMPUTING SUBROUTINES

- Quantum amplitude amplification
- Quantum Fourier Transform (QFT), hidden subgroup finding
- Quantum phase estimation
- Quantum linear algebra subroutines, quantum singular value decomposition
- Other techniques and subroutines, e.g. quantum walks, amplitude estimation

5.5 QUANTUM ALGORITHMS

- Number theory and factorisation (e.g. Shor algorithm)
- Oracular algorithms and database search (e.g. Grover algorithm)
- Linear algebra (e.g. Harrow-Hassidim-Lloyd algorithm)
- Quantum optimisation
- Quantum machine learning, quantum neural networks
- Quantum simulation algorithms
- Noisy intermediate-scale quantum (NISQ) algorithms: Variational Quantum Eigensolver (VQE), Quantum Approximate Optimisation Algorithm (QAOA)

5.6 APPLICATIONS OF QUANTUM COMPUTING AND SIMULATION

- Materials science
  - Manufacturing, e.g. new types of batteries
  - Pharmaceutical drug discovery
  - Catalyst discovery (improvement of chemical processes like Haber-Bosch)
- Engineering and design
  - Simulation of complex processes, e.g. aerodynamics, structural dynamics, crash & safety
  - Computational fluid dynamics, e.g. airflow around aircraft
  - Surrogate machine learning based models for numerical simulations
  - Design optimisation
- Optimisation in finance, production, network and logistics
  - Routing
  - Supply chain management, loading and sizing, production planning
  - Insurance risk assessment
  - Financial portfolio optimisation
  - Satisfiability problems (SAT): possible solutions for a set of constraints
  - Sequencing problems for optimal sequence for executing jobs
- Data security and cryptography

6 QUANTUM SENSORS AND IMAGING SYSTEMS

6.1 BASICS

- Fundamental quantum limits (standard quantum limit, Heisenberg limit)
- Definition of SI units
- Measurement criteria (sensitivity, resolution, etc.), classical alternatives, performance analysis

6.2 ELECTROMAGNETIC FIELD SENSORS

- NV centres, Rydberg atoms, superconducting sensors
- Atomic magnetometers and optically pumped magnetometers (OPMs)

6.3 TEMPERATURE, PARTICLE AND PRESSURE SENSORS

- Spin-qubit based sensors
- Precision spectroscopy gas sensors
- Optomechanical sensors

6.4 INERTIAL AND GRAVITY SENSORS

- Micro-electromechanical sensors (MEMS)
- Atom interferometers
- Rotating nanoparticle sensors

6.5 QUANTUM IMAGING

- Interaction-free measurement
- Quantum ghost imaging, lithography, imaging with undetected photons, tomographic imagin
- Quantum radar, quantum lidar

6.6 ATOMIC CLOCKS

- Microwave clocks, atomic fountain clocks, coherent population trapping (CPT) clocks
- Optical clocks, trapped ion clocks, neutral atoms in optical lattices clocks, quantum logic clocks
- Nuclear clocks
- Transportable atomic clocks

6.7 APPLICATIONS OF QUANTUM SENSORS

- Metrology at a single quantum level
  - Precision spectroscopy, quantum logic spectroscopy
- Medicine and molecular biology
  - Magnetic detection of neuronal and cardiac signals
  - Imaging (e. g. living cells)
  - Microwave diagnostics
- Civil and environmental monitoring
  - Geology, underground surveys, natural resource exploration, archaeology
  - Civil engineering, infrastructure monitoring
  - Earth monitoring, natural hazard prevention
- Transport and navigation, precise timing and position detection
- Control in industrial processes
  - Inspection in microelectronics
  - Ultra-precise timing and synchronisation, reference time

7 QUANTUM COMMUNICATION AND NETWORKS

7.1 BASICS

- Conventional and post-quantum cryptography, combined cryptographic approaches
- Quantum teleportation, Bell state measurement
- Security proof, side-channel attacks

7.2 QUANTUM RANDOM NUMBER GENERATORS (QRNG)

- Secure keys, e. g. for Quantum Key Distribution (QKD)
- Random numbers for algorithms, e. g. online gambling

7.3 QUANTUM KEY DISTRIBUTION (QKD)

- QKD basic protocols, e. g. BB84 (Bennett/Brassard), B92 (Bennett), E91 (Ekert)
- QKD advanced protocols, discrete and continuous variable protocols
- Measurement-device-independent (MDI) QKD and device-independent (DI) QKD
- Quantum key management systems, QKD modules (full devices)

7.4 APPLICATIONS OF QUANTUM CRYPTOGRAPHY

- Sector-specific use cases, e. g. financial transactions, health records, protection of critical infrastructure, e-government, defence, e-commerce, voting
- Secure access to cloud-based quantum computing, delegated quantum computing
- Protection of quantum data (encryption, authentication), advanced primitives (unclonable data, quantum money etc.)
- Quantum remote sensing with secure data transmission

7.5 INFRASTRUCTURE FOR QUANTUM INFORMATION NETWORKS (QUANTUM INTERNET)

- Quantum network nodes, memories and switches
- Quantum repeaters, entanglement swapping, entanglement purification
- Quantum channels, free-space communication, fibre-based systems, satellite-based systems

7.6 SYSTEM NETWORKS (COMPOSITE SYSTEMS), QUANTUM INTERNET APPLICATIONS

- Full quantum communication network, QKD trusted node networks (secure data transfer)
- Quantum enabled synchronisation networks, sensor and clock networks
- Connected and distributed quantum computing

8 VALORISATION

8.1 INDUSTRY LANDSCAPE AND MARKET ANALYSIS (SECTOR LEVEL)

- Market size and growth potential
- Policy and regulatory environment
- Strategic foresight
- Customer trends, needs and preferences

8.2 BUSINESS STRATEGY, ENTREPRENEURSHIP AND MANAGEMENT (BUSINESS LEVEL)

- Governance, leadership, risk management and strategic decisionmaking
- Competitive analysis
- Product and service innovation, Technology Readiness Level (TRL), intellectual property, business model innovation
- Industrial processes, standardisation, evaluation, compliance, benchmarking (application-driven)
- Organisational design, change management and value chain optimisation
- Project and resource management

8.3 IMPACT

- Funding and initiatives landscape
- Economic impact
- Societal and environmental impact
- Scientific impact

8.4 RESPONSIBILITY AND AWARENESS

- Responsibility, ethics
- Public communication and outreach, awareness raising
- Education and training