Funded by the European Union

Certification Scheme for Quantum Technology Proficiency
based on the proficiency levels of the European Competence Framework for Quantum Technologies (CFQT)

Franziska Greinert, Dagmar Hilfert-Rüppell, Rainer Müller

This document provides measurable proficiency level descriptions and sample examinations for Quantum Technology (QT) related competences.

Value and objectives of the certification scheme

Establishing standardised procedures for the certification process guarantees that all participants are assessed under the same conditions, promoting fairness and equity. By this, a professional certification scheme enables continuous monitoring and evaluation of the quality of the professionals and parallel development with the findings/requirements, such as the qualifications of individuals in the quantum workforce. The certification can act as an incentive for professionals to continuously learn and improve their skills, which ultimately benefits the quality of education and access to job opportunities.

Use cases

The certification scheme is based on the CFQT proficiency levels, which were developed through extensive interviews with industry professionals to document the current needs in the labour market. Therefore, this scheme can serve as a valuable basis for institutions, companies and (educational) organisations active in the field of QT. Potential use cases include:

(Educational) institutions offering continuing education programmes and universities:

- *Application:* Educational institutions can use the scheme as a reference to design and update curricular content aimed at the required competences in QT. Competences and content for the award of certificates can be developed on the basis of the scheme. Courses can be mapped and compared to identify the overlap or need for additional courses.
- *Benefit:* This promotes quality and the awarding of standardised documents that certify that relevant qualifications have been acquired that are in demand on the labour market.

Companies in the field of QT:

- *Application:* Companies can use the scheme to create job descriptions, to compare the qualifications of job applicants, and to develop trainings or identify relevant training programmes in (educational) institutions to upskill their employees.
- *Benefit:* This increases the match between employees' qualifications and the actual requirements of the industry, which increases competitiveness.

Individuals:

- *Application:* Individuals can use the scheme to plan and manage their entry into the labour market or to undertake further training that meets the current needs and trends in the field of QT.
- *Benefit:* Individuals can identify their own skills and knowledge and clearly define where they would like to develop professionally. Based on this, they can find suitable programmes and develop a tailor-made training strategy that is optimally aligned with their personal goals and the labour market.

Policy makers and industry associations:

- *Application:* Regulators and associations can use the scheme as a basis for developing standards and guidelines that promote quality assurance in industry.
- *Benefit:* An up-to-date contribution is made to the development of standardised requirements for training in QT-related qualifications.

Structure and background

On the following pages, six proficiency levels A1, A2 (beginner), B1, B2 (intermediate) and C1, C2 (advanced) are described for each of three proficiency areas, including a specification of required knowledge and skills, as in the CFQT. This structure is introduced on the next page.

For each level, the associated content is described and examples are given of how to measure whether someone has reached that level. Example tasks are given for the beginner levels (A1, A2), while assessment scenarios are illustrated for the intermediate and advanced levels. Based on these descriptions and examples, training courses and qualifications can be planned, mapped, and compared.

The examples are not exclusive, the aim is to provide a clearer picture of what is required to reach a specific level. As the proficiency areas are formulated independently of a concrete QT, the focus content needs to be specified additionally. For this, the content map of the CFQT provides a structured overview of relevant topics and concepts. Cross-references to related (sub)domains of the content map are given in the content descriptions.

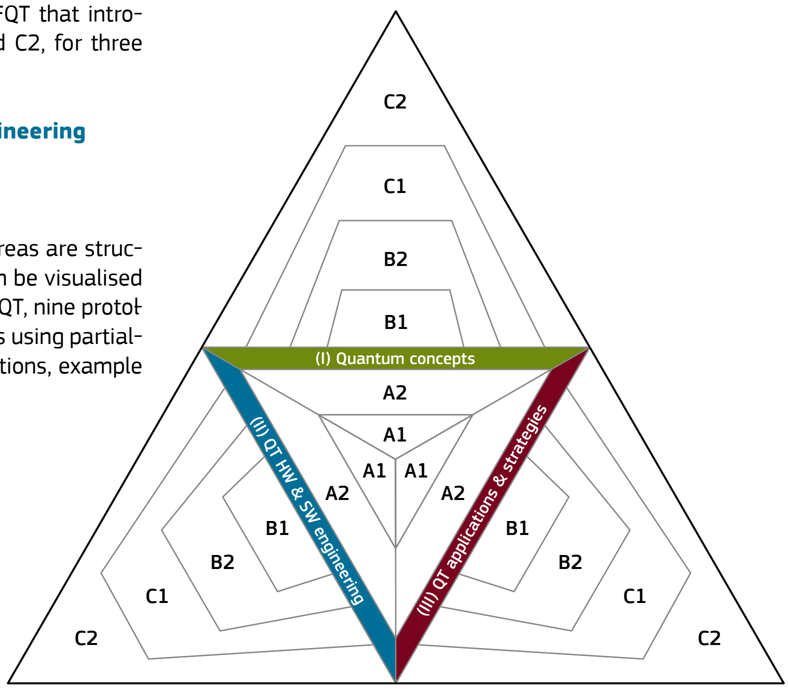
Typically, the objectives of a course or the qualification of an individual cover (different) proficiency levels in all three proficiency areas, and a number of topics from the content map. Examples are also given in the CFQT.

More details and the latest version of the CFQT are available at DOI 10.5281/zenodo.6834598.

Certification Scheme for QT Proficiency
Structure

The backbone of the certification scheme is the CFQT that introduces six proficiency levels A1, A2, B1, B2, C1, and C2, for three proficiency areas:
(I) Quantum concepts
(II) QT hardware and software (HW & SW) engineering
(III) QT applications & strategies

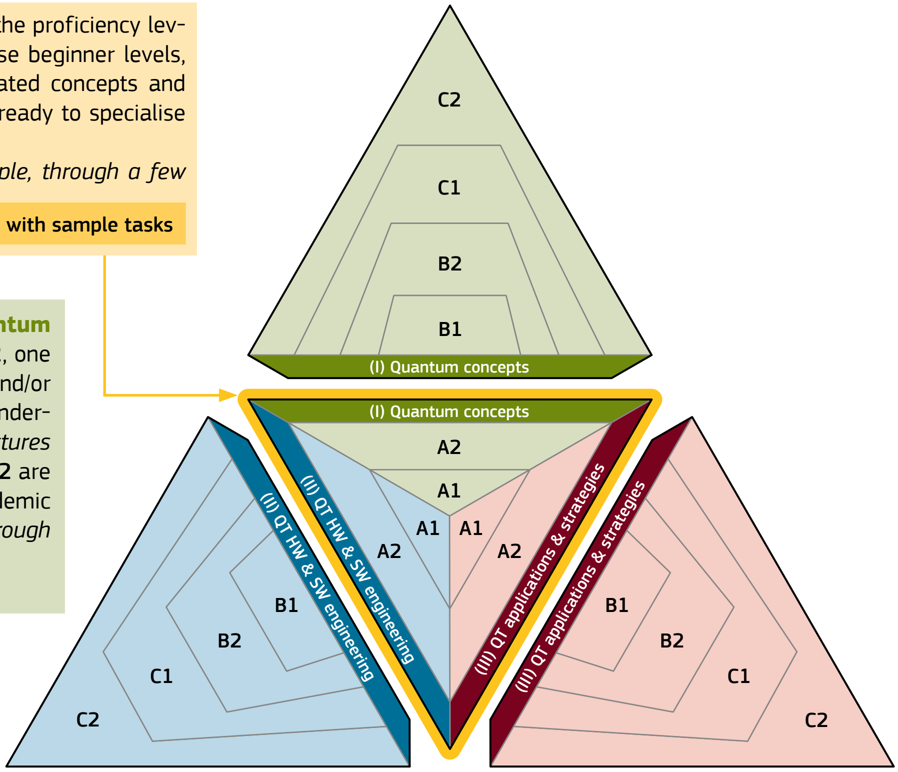
The six proficiency levels for the three proficiency areas are structured in the **Proficiency Triangle**. A qualification can be visualised by a partially coloured proficiency triangle. In the CFQT, nine prototypical qualification profiles show such qualifications using partially coloured proficiency triangles with profile descriptions, example personas, and related needs and suggestions.



In the centre of the proficiency triangle are the proficiency levels **A1 Awareness and A2 Literacy**. At these beginner levels, one gains a basic overview of QT with related concepts and applications. To be QT literate means to be ready to specialise in one or more proficiency areas and topics.
Such proficiency can be achieved, for example, through a few days of instruction or self-study.
Details on p. 3.

with sample tasks

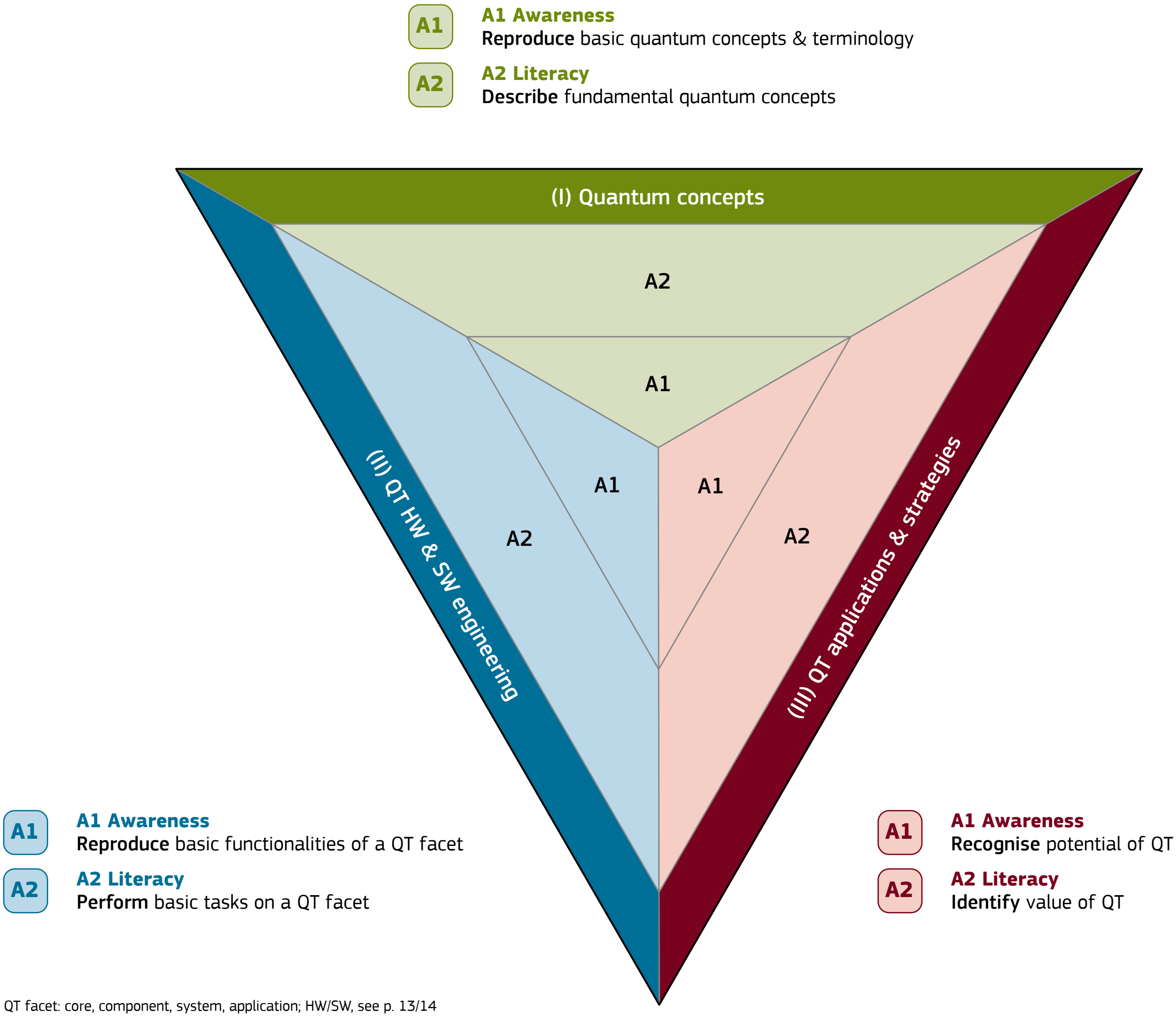
The first proficiency area focuses on **(I) Quantum concepts**. At the **intermediate levels B1/B2**, one begins to specialise in quantum physics and/or quantum information science, including the underlying mathematics, e.g. *through university lectures or longer courses*. The **advanced levels C1/C2** are typically associated with fundamental/academic research, e.g. a C2 level may be *reached through a doctoral project.*
Details on p. 10.



The second proficiency area focuses on **(II) QT HW & SW engineering**. It covers both, hardware and software focused engineering, as well as aspects of systems engineering and technology realisation. The **intermediate levels B1/B2** qualify for practical and analytical autonomous work on QT. The **advanced levels C1/C2** consider the whole system and also research aspects. Achieving these levels may require *focused training and learning on the job, with assessment of work quality by experts.*
Details on p. 13.

The third proficiency area focuses on **(III) QT applications & strategies**. It covers the business perspective, such as market and strategy assessment, but also impact and responsibility as well as education and workforce development. Such a proficiency typically relies on *experience, formal and informal learning, networking, and communication with a variety of experts to handle complex situations.*
Details on p. 16.

Certification Scheme for QT Proficiency: Basics
up to QT literacy



QT facet: core, component, system, application; HW/SW, see p. 13/14

A1 Awareness

covers the basic idea of QT and how they work (area (II)), with the corresponding terminology (area (I)) and an idea of the potential and limitations of technological applications (area (III)). A workshop or a short online course may address one or all three of these proficiency areas, and cover topics from one or several QT pillars (content domains 5, 6, 7, see p. 13). It can also focus on a concrete application and/or application field, e.g. if addressing decision makers.

Examination may cover multiple-choice questions or questions that require short reproductions of introduced definitions or examples.

A certificate is rather a proof of attendance, and it is beneficial for learners to gain access to these basics in their own language.

A2 Literacy

covers a broader overview, conducting first practical tasks with supervision and direct feedback, and reproducing solutions and processes as previously learned.

Examination may cover advanced multiple-choice questions, but suggested are open-format questions where learners have to explain their solution, perform a calculation or practical task.

Certificates become important if a practical skill is trained, such as using a HW device or a SW programme appropriately. This skill needs to be explicitly stated on the certificate.

Related content (sub)domains

for the three proficiency areas are given on the pages 10, 13 and 16 introducing the specialisation, i.e. B and C levels, for each of the proficiency areas separately.

Objectives for level A1 in (I) Quantum concepts

A1 Awareness: Reproduce basic quantum concepts & terminology
K: Basic idea (phenomena-oriented) of elementary quantum concepts with the corresponding terminology.
S: Ability to identify basic quantum concepts and assign the appropriate term, e.g. to follow (media) conversations about quantum.

Contents: Basic quantum concepts (1.1), including e.g. superposition, interference, measurement process, decoherence, complementarity, entanglement.
Introduction to these concepts focussing on the phenomena, the effects that occur, the terminology that is used, to enable a basic understanding and appropriate use of the vocabulary. Enable people to follow conversations of colleagues or in public media with an idea of the basic concepts and terminology.
May include fundamental experiments and its interpretations, but not mathematical descriptions, calculations or similar.

Sample examination

1. *Match quantum concept description and name:* Descriptions for three basic quantum concepts (e.g. superposition, decoherence and entanglement) are given as well as the names of these concepts. Assign the correct name to each description.
2. *Distinguish between several basic quantum concepts:* Multiple-choice questions, e.g. several descriptions and select all those describing examples for superposition.
3. *Remember the name for a described quantum concept:* The description of a quantum concept is given, answer with the technical term for the concept.
4. *Reproduce a basic description for a quantum concept:* For a given quantum concept, e.g. superposition, give a short description as previously learned.

Sample tasks

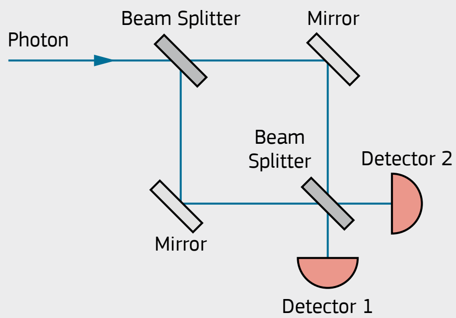
I.A1.
Task 1:
Match each description with the correct technical term.

Descriptions:
1. This refers to a quantum system being in a state that is a combination of different possible outcomes, with measurement determining which one is realised. ☐
2. This phenomenon occurs when two or more objects share a quantum state such that measuring one provides information about the other, even if they are separated by large distances. ☐
3. This is the process by which quantum systems lose their coherence and behave more classically due to interactions with the environment. ☐

Terms:
A. Decoherence
B. Superposition
C. Entanglement

(Answer: 1-B/2-C/3-A)

Task 2:
Name the main quantum phenomena that occur in the experimental setup.



(Answer: superposition and interference)

Task 3:
Reproduce a basic description for a quantum concept.

Give a short description of the effect of decoherence, e.g., in the context of Schrödinger's cat.

(Answer, e.g.: Decoherence describes the effect that quantum phenomena like superposition does not occur in our macroscopic world, i.e., a cat cannot be in a superposition state of being dead and being alive.)

Task 4:
Select all** descriptions that exemplify **superposition effects.

- ☐ a. A photon can be in a superposition state of horizontal and vertical polarisation.
- ☐ b. An electron can be in a superposition state of spin up and spin down.
- ☐ c. An ion can be in a superposition state of spin down and horizontal polarisation.
- ☐ d. A cat can be in a superposition state of dead and alive.

(Correct choices: a. and b.)

Objectives for level A1 in (II) QT HW & SW engineering

A1 Awareness: Reproduce basic functionalities of a QT facet
K: Basic idea of the functionalities of a QT facet.
S: Ability to follow basic instructions or conversations on the QT facet; reproduce basic processes.

Contents: Functionalities of QT facets from one or several QT domains (5, 6, 7), e.g. basic quantum gates (5.1), magnetic field measurement with NV centres (6.2), BB84 protocol (7.3).
Introduction to one or several QT pillars with example applications and/or components with a focus on the functionality or working principles, including practical/hands-on tasks, with simulators/demonstrational experiments or real devices.

Sample examination

1. *Name quantum gate for an effect:* For a given effect (e.g. create superposition), name the quantum gate that causes this effect.
2. *List basic quantum gates:* List the technical terms for the basic quantum gates introduced.
3. *Sort gates and functionalities:* For basic quantum gates, sort name and functionality description.
4. *Name measurable properties or related quantum sensor:* For a given quantum sensor, name the physical properties that can be measured, or the other way around (for the property, name a quantum sensor that can be used to measure it).
5. *List steps of a protocol:* For the BB84 protocol, list the steps that are needed to conduct the process.
6. *Reproduce a basic description of a functionality:* For a quantum gate or algorithm or measurement process or protocol step or…, give a short description.

Sample tasks

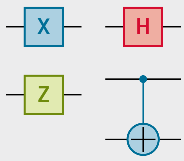
II.A1.
Task 1: *(computing)*
Name the basic quantum gate needed to create superposition states.

(Answer: Hadamard gate)

Task 2: *(computing)*
Sort the following gates by their functional description:

(Correct order: X gate – Z gate – Hadamard gate – CX gate)

Functionality Description	Quantum Gate
Flips the state of a qubit ($0 \leftrightarrow 1$)	
Applies a phase shift of π to the state	
Creates superposition	
Flips the target if control is 1	



Task 3: *(sensing)*
Why do superconducting quantum sensors need a cryogenic environment to work? ***Select the correct answer.***

☐ a. Because they are not sensitive enough at room temperature.
☐ b. Because they need low temperatures to become superconducting.
☐ c. Because they look much cooler.

(Correct choice: b)

Task 4: *(sensing)*
Name the physical property that can be measured with an NV center sensor.

(Answer: magnetic field)

Task 5: *(communication)*
What is the BB84 protocol used for? ***Select the correct answer.***

☐ a. Send a message directly.
☐ b. Create a physically secure key to encrypt a message.
☐ c. Identify the best baseball player within a selection of 84 games.

(Correct choice: b)

Task 6: *(communication)*
Sort the following steps of the BB84 protocol into the correct order:

☐ a. Alice sends a photon to Bob.
☐ b. Alice and Bob communicate about the basis selection.
☐ c. Alice selects a preparation basis and prepares a photon in one of these basis states (randomly).
☐ d. Bob selects a measurement basis and measures the photon.

(Correct order: c – a – d – b)

Objectives for level A1 in (III) QT applications & strategies

A1 Awareness: Recognise potential of QT
K: Basic idea of the potential of QT systems and applications, overview of possibilities, challenges and limitations.
S: Ability to follow public media and discussions with critical awareness of hype.

Contents: Applications of one or several QT domains (5.6, 6.7, 7.4, 7.6), or a selected (sub)topic (concrete field of application, e.g. quantum optimisation in logistics from subdomain 5.6).
Focus on impact (8.3) and relevance for business (8.2, e.g., the own sector); with realistic expectations and critical view on hype (8.4, especially for computing).
Introduction on (potential) use cases with relations to a branch with remarks on challenges and limitations, together with considerations of (positive and negative) impact and discussion of these QT in public media to create awareness of hype.

Alternative *QT in education and communication* (8.4): Focus on didactically selected examples of QT applications and how they can be used in educational context with critical reflection on the impact on (mis)conceptions and attitudes towards QT, covering also the consideration of hype, e.g., to prevent public communication with hyped-up metaphors.

Sample examination

1. *Select potential applications or limitations:* Multiple choice format to pick from several statements those that are in line with current expectations on QT.
2. *Name challenges:* For a QT application, name fundamental challenges to bring them to industrial readiness.
3. *List potential of QT:* List potential advantages and impact of QT, a QT pillar, a QT application, or similar.
4. *Reflect on hype:* For a public media article, identify hyped wording and unscientific statements.

Sample tasks

III.A1.
Task 1: *(computing/communication)*
***Tick all statements that are in line** with current expectations on future quantum information technologies:*

- ☐ a. Quantum computers will be the new supercomputers, in a few years, we will not need or use any more classical computers.
- ☐ b. Quantum computers will solve very special problems that may have high impact on the whole society.
- ☐ c. New cryptography approaches are needed that cannot be broken by quantum computers.
- ☐ d. Quantum key distribution is the only approach to be safe against attacks from quantum computers.
- ☐ e. Quantum computing and simulation are expected to impact, e.g., pharmacy, finance, logistics and machine learning.

(Correct choice: b, c, e)

Task 2:
***Select the option that is NOT a challenge** in developing quantum technologies into an industrial product:*

- ☐ a. Miniaturisation and scaling
- ☐ b. Qubit and gate quality
- ☐ c. Availability of quantum objects to be used as a qubit
- ☐ d. Workforce/talent scarcity

(Correct choice: c)

Task 3:
List two potential advantages and impacts of Quantum Technologies.

Possible answers, e.g.:
1. *Fast computations (optimisation problems)*
2. *Unbreakable encryption (quantum key distribution)*
3. *Advanced sensors (medical imaging, navigation)*
4. *Drug discovery (accurate simulations of molecular interactions)*

Task 4:
*For the given public media article, identify hyped wording and unscientific statements present. **Circle the words that seem exaggerated or unscientific.***
Media article:

**Quantum Technology:
The Ultimate Key to a Perfect Future?**

In a groundbreaking leap forward, scientists have unveiled the secrets of Quantum Technology, a revolutionary field that promises to change the world as we know it. Experts claim that with quantum computers, we will soon harness the power to solve any problem - from curing diseases to eradicating poverty. This extraordinary technology is on the brink of unleashing unlimited potential, enabling humanity to tackle the toughest challenges facing our planet. That is because quantum computers throw out several results in parallel.

And quantum computers can decode everything! However, scientists have a solution: quantum communication guarantees that your online information is completely unhackable. With this next-level encryption, hackers will be a thing of the past, and your personal data will be more secure than ever. Forget relying on outdated security measures - quantum technology is set to create an impenetrable fortress around our digital lives. Are we prepared to embrace this new era using these magical technologies?

Answer:

**Quantum Technology:
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Objectives for level A2 in (I) Quantum concepts

A2 Literacy: Describe fundamental quantum concepts with appropriate terminology, e.g. in conversations
K: Knowledge of fundamental quantum concepts with underlying mathematical formalism and/or representations.
S: Ability to explain basic quantum concepts and describe them using basic mathematics and/or representations as well as appropriate terminology, e.g. to communicate with quantum experts and novices.

Contents: Quantum concepts and related mathematical foundations (domain 1), including e.g. the Dirac notation, quantum states, and the concept of a qubit, with the related quantum effects, e.g. superposition states for a qubit and how they can be visualised, or decoherence and how they affect a quantum state, or the mathematical description of entanglement.
Introduction typically based on fundamental experiments and its mathematical descriptions, or together with an introduction to QT systems and applications, covering also A1 level in proficiency area (II).

Sample examination

1. *Describe a quantum concept:* For a given quantum concept, formulate a description including, e.g., the mathematical description or the typical related experiment.
2. *Calculate a quantity for a simple problem:* For a simple situation, calculate the quantum state/measurement probability/..., e.g. for a qubit in the Dirac formalism, as previously learned.
3. *Describe an experiment:* For a given experiment, e.g. the double slit experiment, explain which quantum effects contribute to the observed results.
4. *Identify correct/wrong items:* Multiple choice question with complex items, e.g., four descriptions or interpretations, of which the correct (or the wrong) has to be selected.

Sample tasks

I.A2.
Task 1:
Describe the concept of entanglement, give an entangled two-qubit state in the Dirac notation and show that it is entangled.

(Answer, e.g.: Entangled states of multiple qubits are non-separable, i.e. they cannot be expressed as a product of the states of the individual qubits. This causes correlations in the measurement of the states of the qubits that cannot be explained classically. An example is the two-qubit state $|\Psi^+\rangle = \frac{1}{\sqrt{2}}(|+-\rangle + |-+\rangle)$. If this state were separable, it must be possible to write it as the tensor product of two on-qubit states:

$$\begin{aligned}|\psi_1\rangle \otimes |\psi_2\rangle &= (a\,|+\rangle + b\,|-\rangle) \otimes (c\,|+\rangle + d\,|-\rangle)\\ &= ac\,|++\rangle + ad\,|+-\rangle + bc\,|-+\rangle + bd\,|--\rangle\end{aligned}$$

leading to the four conditions: $ac \overset{!}{=} 0$, $ad \overset{!}{=} \frac{1}{\sqrt{2}}$, $bc \overset{!}{=} \frac{1}{\sqrt{2}}$, $bd \overset{!}{=} 0$.
It follows from the first condition that at least one of the factors a and c must be zero. For $a = 0$, the second condition cannot be fulfilled and, similarly, $c = 0$ contradicts the third condition. So there are no coefficients a, b, c, d that satisfy all four conditions. A factorisation is not possible, thus, the state $|\Psi^+\rangle$ is entangled.)

Task 2:
Calculate the quantum state: *A horizontally polarized photon enters a setup of two polarisers, with the first polariser oriented at a 45° angle and the second polariser oriented at a 90° angle, i.e. vertically. Note the quantum state of the photon after being transmitted by both polarisers and calculate the probability for this event.*

(Answer, e.g.: The state after the first polariser is $|+\rangle = \cos(45°)\,|H\rangle + \sin(45°)\,|V\rangle$. The probability of a photon in state $|H\rangle$ to be transmitted and thus in this state after the polariser is

$$P(+) = |\langle +|H\rangle|^2 = \frac{1}{2}|\underbrace{\langle H|H\rangle}_{=1} + \underbrace{\langle V|H\rangle}_{=0}|^2 = \frac{1}{2}$$

The state after the second polariser is $|V\rangle$ and the probability of a photon passing this polariser after passing the first polariser is

$$P(V,+) = P(V)P(+) = |\langle V|+\rangle|^2 |\langle +|H\rangle|^2 = \frac{1}{2}\frac{1}{2} = \frac{1}{4}$$

Thus, the probability of a horizontally polarized photon to pass both polarisers is 25 %.)

Task 3:
Interpret the measurement. *Consider an ideal setup of a Mach-Zehnder interferometer with two detectors, D1 and D2, in which photons are always detected at D1. Now the setup is slightly modified so that every photon is detected at D2. What can be deduced from this observation?*

(Answer, e.g.: The path length of the two partial beams in the interferometer has been changed by half a wavelength, or (n+1/2) wavelengths for an integer n.)

Task 4:
Identify the wrong description: ***Select all wrong*** *descriptions of quantum concepts.*

☐ a. The unitary matrix $U_{\mathrm{BS}} = \begin{pmatrix} 1 & i \\ i & 1 \end{pmatrix}$ describes the action of a symmetric beam splitter
☐ b. The states $|\Psi^+\rangle = \frac{1}{\sqrt{2}}(|+-\rangle + |-+\rangle)$ and $|\Psi^-\rangle = \frac{1}{\sqrt{2}}(|+-\rangle - |-+\rangle)$ form a basis.
☐ c. A qubit is a ‘quadratic bit’, in contrast to a classical bit that can be in the states 0 or 1, a qubit has four potential states.
☐ d. Even though quantum objects in a superposition state do not need to have a fixed value of the measured quantity, a measurement always yields a definite result.

(Correct choices, i.e. wrong descriptions: a and c; in a, the factor of $\frac{1}{\sqrt{2}}$ is missing for unitarity, and qubit is for ‘quantum bit’ that allows for – more than four – possible superposition states.)

Objectives for level A2 in (II) QT HW & SW engineering

A2 Literacy: Perform basic tasks on a QT facet
K: Knowledge of fundamental working principles of different parts in the context of a QT facet and how they can be used (technically), focusing on the difference to classical counterparts.
S: Ability to perform practical tasks (operate) with the QT facet (work in a lab or with software).

Contents: Details on functionalities of QT facets from one or several QT domains (5, 6, 7), including related hardware (4) and/or enabling technologies with basic laboratory techniques (3). For Example: what is needed for quantum state control 4.6 or quantum programming tools 5.3 or what is needed for quantum imaging 6.5 or …
Overview in one or several QT pillars with applications and/or components. Focus on the functionality or working principles and the differences to classical counterparts, including practical/hands-on tasks.

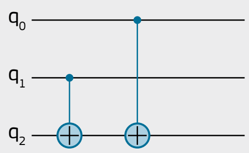
Sample examination

1. *Describe a working principle:* Describe the functionality of a quantum algorithm/sensor/cryptography protocol.
2. *Operate the QT facet (HW or SW) appropriately as previously trained:* Perform basic practical tasks, e.g., with a sensor, or basic programming tasks.
3. *Explain a setup:* For an experimental setup, e.g., a demonstrator for quantum key distribution, name the components and explain the role of the components for the functionality.
4. *Compare quantum and classical approach:* Describe the main technological differences and similarities between a QT facet and the classical counterpart, thus compare the functionality of, e.g., a quantum sensor under development with current state-of-the-art sensing technologies, or a quantum algorithm with classical opportunities to address the corresponding problem.

Sample tasks

II.A2.
Task 1: *(computing)*
Draw a quantum circuit to compare two qubits and describe the functionality.
Use q_0 and q_1 as the input qubits that should be compared, q_2 as the ancilla qubit prepared in state $|0\rangle$. (Principally known from the previous instruction; could be combined with a mathematical proof if also level B1 in area (I) on the mathematical formalism is covered)

(Answer:

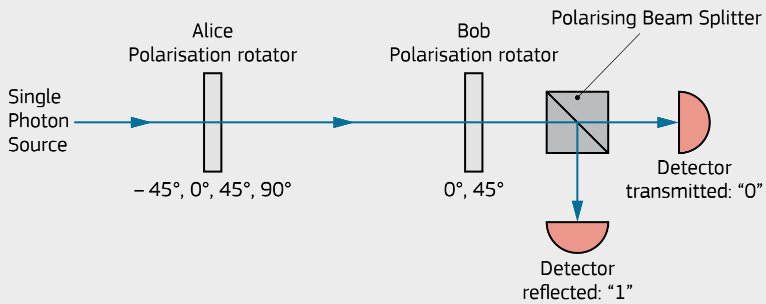


The CX gate is self-inverse, if both input qubits are equal, the second CX gate reverses the effect of the first one. Thus, if the input qubit states are equal, the state of the ancilla qubit is $|0\rangle$. If the input states would be $|0\rangle$ and $|1\rangle$, for example, the ancilla qubit would be in state $|1\rangle$.)

Task 2: *(sensing)*
Perform a measurement with an NV center sensor: *Use an NV-center based magnetometer (demonstrator) to perform a measurement of a magnetic field. Record the measurement data and interpret the result.*

(Practical task after instruction, including: interpret distance of minima in the fluorescence rate regarding the determination of the magnetic field.)

Task 3: *(communication, after conducting the experiment in the instruction)*
Describe the setup *for the BB84 protocol shown in the figure.* ***Explain the role of each component.***



(Answer, e.g.: For the BB84 protocol, a sender unit (Alice) and a receiver unit (Bob) are required. The sender unit has a single photon source and a polarisation rotator. They are needed to prepare photons in four possible states, i.e. polarisation directions of 0° and 90° as the two states of the first basis, and +45° and -45° as the two states of the second basis. Alice chooses randomly between the two bases and which of the two possible states in this basis she sends. The receiver unit has another polarisation rotator with two possible directions. This is needed to perform the measure in both bases that Alice can use to send the photon states. After the polariser, a polarising beam splitter and two detectors are used to measure both possible states in the selected basis.)

Objectives for level A2 in (III) QT applications & strategies

A2 Literacy: Identify value of QT
K: Knowledge of applications landscape (e.g. products on market) and use cases as well as expected technological development (impact, timelines) and ethical implications.
S: Ability to identify potential use cases (i.e. opportunities for value creation, where to seek expert assessment).

Contents: Applications of one or several QT domains (5.6, 6.7, 7.4, 7.6), or a selected (sub)topic (as on A1 level) Focus on potential applications with expectations, including (not only) economic impact and responsibility issues (8.3) Showcase (potential) use cases with related business value (8.2), for the own company or the sector in general.

Alternative *QT in education and communication* (8.4): Focus on how QT applications can be used as contexts to convey quantum concepts, e.g., the quantum teleportation protocol for entanglement, no-cloning, measurement process, … for example to use them in public communication and outreach efforts, industry exhibitions, …

Sample examination

1. *Describe expected impact:* For a QT application, describe the expected impact for a specific company or an industrial sector, the whole society or the environment, for example (generic description without analysis).
2. *Outline expectations and timelines:* For a given QT system or application, give a short description of the expected technological development including a rough timeline (as introduced in a previous training).
3. *Identify potential fields for application:* Describe principle potential (without verification).
4. *Give examples of potential use cases for a given QT system or application.*
5. *Contrast the potential of a QT system to a non-quantum state-of-the-art technology:* List pros and cons for both technological approaches and highlight the advances and challenges of the quantum system (after getting the relevant information in a training, for example).

Sample tasks

II.A2.
Task 1: *(computing)*
Describe the expected impact of quantum computing breaking current cryptography. *Give one examples each of how this would impact industry, government and the whole society.*

(Answer may include encrypting…
- company secrets
- plans regarding national security and defence
- personal data, e.g., health or banking

or other examples, in full sentences describing the consequences.)

Task 2: *(sensing)*
Identify potential application of quantum sensors or imaging technologies in the medical sector. *Give a short description of two (existing or) commonly discussed potential applications or use cases and describe two related ethical considerations for the use of QT in the medical sector.*

(Answer may include:
- measuring brain activity with optically pumped magnetometers (OPM)
- imaging of tumor cells within cancer diagnostic with magnetic resonance imaging (MRI)

and
- equity access to care
- informed consent of the patient

or other examples, in full sentences describing the consequences.)

Task 3: *(communication)*
Contrast QKD and PQC: *List two pros and two cons each of quantum communication using QKD (quantum key distribution) and PQC (post quantum cryptography) to contrast the advantages and disadvantages of the two approaches.*

(Answer may include:

Pros QKD:
- physically secure
- detection of eavesdroppers

Cons QKD:
- technological challenges, e.g., quantum repeater
- need for additional fibers and other infrastructure

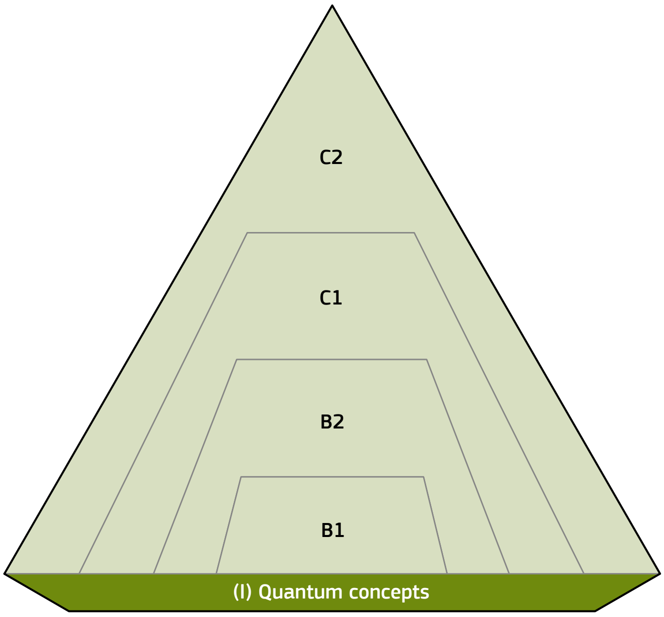
Cons PQC:
- security based on current expectations on what quantum computers may break
- no inherent detection of eavesdropping attempts

Pros PQC:
- ready to use, already implemented by some companies
- use of standard classical hardware

or other (dis)advantages, in a structured list.)

Certification Scheme for QT Proficiency: area (I)

Focus on the underlying concepts (quantum physics etc.)



B1 **B1 Utilisation**
Apply quantum methods to problems

B2 **B2 Investigation**
Analyse problems with quantum

C1 **C1 Specialisation**
Refine and extend quantum methods

C2 **C2 Innovation**
Develop innovative solutions

Proficiency area **(I) quantum concepts** focuses on the quantum theoretical foundations of QT, including physics (domain 2) but also underlying mathematics and foundations of information theory (subdomain 1.2). These are the foundations for QT hardware or also for quantum algorithms, depending on the focus contents.

Important skills are similar to those in theoretical physics and mathematics: applying and extending scientific methods to model and solve problems.

Typical formats to convey these concepts at an intermediate level (B1 or B2) are lectures with (homework) exercises and a written exam or a small (student) research project with documentation.

Further specialisation would require independent and autonomous learning, reading research papers and conducting, presenting and documenting one's own research, as in a PhD programme in quantum physics (C2).

Research may require competences in domain 3, falling into proficiency in area **(II)**, such as laboratory techniques or programming.

Typically, basic or intermediate proficiency in the other proficiency areas will be required to reach the advanced proficiency levels in one proficiency area.

Related content: extract from the CFQT content map

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 physics
- 2.4 Quantum many-body systems and open quantum systems

Topics for the subdomains available in the CFQT, DOI 10.5281/zenodo.6834598, p. 6–7

Objectives for level B1 in (I) Quantum concepts

B1 Utilisation: Apply quantum methods to a variety of theoretical problems
K: Knowledge of a variety of quantum (physics) concepts, including the mathematical formalism, specialised knowledge in a selected subdomain.
S: Ability to describe abstract problems with quantum physics and/or mathematics, solve them with quantum physical and/or mathematical methods.

Contents: Advanced quantum concepts and related mathematical foundations (domain 1), together with some specialisation: (a) in a quantum physics subdomain, e.g. atomic physics 2.1, quantum optics and QED 2.2, solid-state physics 2.3, … or (b) QT-relevant information theory 1.2 or similar. Besides more complex concepts and mathematics, at this level typically starts the specialisation, i.e. contents from one subdomain are in the focus, in other subdomains proficiency may also grow, but more slowly than in the focus subdomain. Also, this level may be reached for several subdomains, e.g., in a university lecture on theoretical quantum physics or quantum information theory.

Sample examination

1. *Calculate expectation values or similar:* Perform advanced calculations, e.g. in the context of energy levels and the Schrödinger equation, or for quantum optics settings, or in quantum electrodynamics, or in a spin system, or …
2. *Model a setup mathematically:* Describe a previously unknown (for example interferometric) setup using mathematics and calculate the expected quantum state for each step in the setup.
3. *Show/prove a mathematical relation:* For a given relation, use mathematical methods to show that it is correct.
4. *Interpret the (measurement) result:* For a calculation or a model of a system or an experiment or an algorithm or …, interpret the result, i.e. what would be the expected outcome of implementing such an experiment or similar, compare experimental results with theoretical expectations.

The tasks may have a QT-related context, e.g., instead of calculating the state after an interferometer (task 1), the effect of a series of quantum gates could be calculated for a given state and the result interpreted, i.e. also covering A2 level of proficiency area (II).

Sample tasks

I.B1.
Task 1:
Calculate the expectation values of the operators *$\hat{S}_x$, $\hat{S}_y$ and $\hat{S}_z$ in the (spin) state $|\Psi\rangle = |\vec{n},+\rangle = \cos\left(\frac{\theta}{2}\right)|e_z,+\rangle + \sin\left(\frac{\theta}{2}\right)e^{i\varphi}|e_z,-\rangle$ with the spin projection $+\frac{\hbar}{2}$ in a general direction $\vec{n}$.*

(Answer: We express the operator in the eigenbasis $|e_z,+\rangle$, $|e_z,-\rangle$ and then calculate the expectation value:

$$\hat{S}_x = \frac{\hbar}{2}\left(|e_z,+\rangle\langle e_z,-| + |e_z,-\rangle\langle e_z,+|\right) \cong \frac{\hbar}{2}\begin{pmatrix}0 & 1\\ 1 & 0\end{pmatrix}$$

$$\begin{aligned}
\langle\hat{S}_x\rangle_{|\Psi\rangle} &= \left\langle\Psi\left|\frac{\hbar}{2}\left(|\,e_z,+\rangle\langle e_z,-\,| + |\,e_z,-\rangle\langle e_z,+\,|\right)\right|\Psi\right\rangle\\
&= \frac{\hbar}{2}\left(\langle\Psi\,|\,e_z,+\rangle\langle e_z,-|\Psi\rangle + \langle\Psi|e_z,-\rangle\langle e_z,+|\Psi\rangle\right)\\
&= \frac{\hbar}{2}\left(\underbrace{\cos\left(\frac{\theta}{2}\right)\sin\left(\frac{\theta}{2}\right)}_{=\frac{\sin(\theta)}{2}}e^{i\varphi} + \cos\left(\frac{\theta}{2}\right)\sin\left(\frac{\theta}{2}\right)e^{-i\varphi}\right)\\
&= \frac{\hbar}{2}\frac{\sin(\theta)}{2}\underbrace{\left(e^{i\varphi} - e^{-i\varphi}\right)}_{=2\cos(\varphi)} = \frac{\hbar}{2}\sin(\theta)\cos(\varphi)
\end{aligned}$$

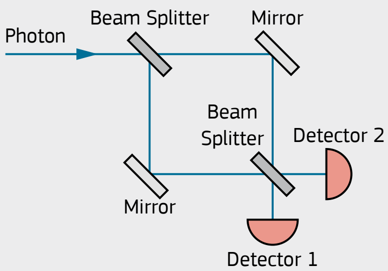
The other two calculations are carried out in the same way and result in …

$$\langle\hat{S}_y\rangle_{|\Psi\rangle} = \frac{\hbar}{2}\sin(\theta)\sin(\varphi)$$

$$\langle\hat{S}_z\rangle_{|\Psi\rangle} = \frac{\hbar}{2}\cos(\theta)$$

Task 2:
Model a Mach-Zehnder interferometer. *Draw a Mach-Zehnder interferometer, name the components and the mathematical operators to describe the components, and calculate the state after the interferometer for an incoming state $|H\rangle$. Interpret the results and discuss the difference between an ideal model and what would be expected in a real setup.*

(Answer:



The operators to describe the components are:

$U_{\mathrm{BS}} = \frac{1}{\sqrt{2}}\begin{pmatrix}1 & i\\ i & 1\end{pmatrix}$ for the beam splitter and

$U_{\mathrm{M}} = \begin{pmatrix}0 & 1\\ 1 & 0\end{pmatrix}$ for the mirrors with the

incoming state $|H\rangle = \begin{pmatrix}1\\ 0\end{pmatrix}$

The state after the interferometer is
$|\psi\rangle = U_{\mathrm{BS}}U_{\mathrm{M}}U_{\mathrm{BS}}|H\rangle$

$$\begin{aligned}
&= \frac{1}{\sqrt{2}}\begin{pmatrix}1 & i\\ i & 1\end{pmatrix}\begin{pmatrix}0 & 1\\ 1 & 0\end{pmatrix}\frac{1}{\sqrt{2}}\begin{pmatrix}1 & i\\ i & 1\end{pmatrix}\begin{pmatrix}1\\ 0\end{pmatrix}\\
&= \frac{1}{2}\begin{pmatrix}1 & i\\ i & 1\end{pmatrix}\begin{pmatrix}0 & 1\\ 1 & 0\end{pmatrix}\begin{pmatrix}1\\ i\end{pmatrix}\\
&= \frac{1}{2}\begin{pmatrix}1 & i\\ i & 1\end{pmatrix}\begin{pmatrix}i\\ 1\end{pmatrix}\\
&= \frac{1}{2}\begin{pmatrix}i+i\\ i^2+1\end{pmatrix} = \frac{1}{2}\begin{pmatrix}2i\\ -1+1\end{pmatrix} = i\begin{pmatrix}1\\ 0\end{pmatrix} = i\,|H\rangle
\end{aligned}$$

In an ideal setup with equal path length, the photon would be always detected on one detector. In a real setup, we have to expect errors, e.g., blind counts, leading to a countnumber higher than zero in the other detector.)

Objectives for level B2 in (I) Quantum concepts

B2 Investigation: Analyse real-world problems with quantum methods
K: Advanced knowledge in a quantum (physics) subdomain, including a variety of methods and their validity.
S: Ability to describe and analyse real-world problems with mathematics, select quantum (physics/mathematics) methods to use to solve them; ensure quantum (physical) requirements are met.

Contents: Similar to content at level B1, with a focus on real-world problems ((advanced quantum concepts and related mathematical foundations (domain 1), together with some specialisation: (a) in a quantum physics subdomain, e.g. atomic physics 2.1, quantum optics and electrodynamics 2.2, solid-state physics 2.3, … or (b) QT-relevant information theory 1.2 or similar.))

Qualifying works for proficiency verification

Short research project with documentation, e.g.
1. Student research project,
2. Bachelor thesis,
3. Basic contribution to a scientific publication.

Requires some autonomy and basic research work, e.g., literature review.

Objectives for level C1 in (I) Quantum concepts

C1 Specialisation: Refine and extend quantum methods to solve new problems
K: Highly specialised knowledge in one subdomain and critical awareness of connections between different subdomains.
S: Ability to refine or extend solutions for new problems (e.g., real-world use cases), using quantum physical and/or mathematical methods and incorporating methods from different subdomains to generate new methods.

Contents: Typically the "traditional" quantum physicist (theoretical). The specialisation pursued at B levels is continued, with the inclusion of various subdomains 2.X and beyond, e.g., quantum chemistry.
Alternative focus: Quantum information science.

Qualifying works for proficiency verification

Research project with documentation, e.g.
1. Master thesis,
2. Major contribution to a scientific publication (research paper), including data analysis and manuscript preparation,
3. Major contribution to industrial research and development, including documentation.

Requires autonomous learning, research experience and scientific writing.

Objectives for level C2 in (I) Quantum concepts

C2 Innovation: Develop innovative solutions for critical problems
K: State-of-the-art knowledge in the subdomain and about connections with different approaches and (sub)domains.
S: Ability to find or develop innovative solutions for critical problems or real-world use cases; to evaluate and assess solutions (based on theoretical physics and mathematics), thus verify advantage; to extend and redefine knowledge or professional practice.

Contents: Similar to contents at C1 level, with research at the frontier of the subdomain considering connections with other subdomains, typically includes the building of expertise also in these subdomains, e.g., to B1 or B2 level.

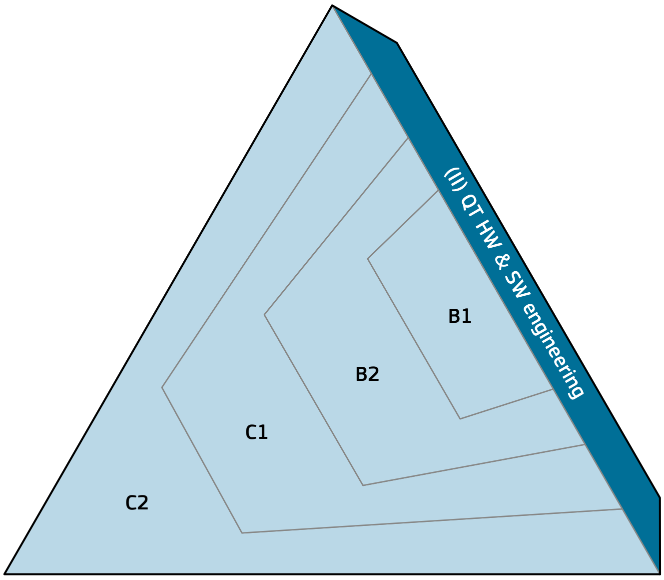
Qualifying works for proficiency verification

Long research project on innovative, new developments with scientific publications, e.g.
1. PhD,
2. Own research publications, including responsibility for documentation and publication process, presentation at conference,
3. Lead role in industrial research and development, including documentation and dissemination.

Requires autonomy and advanced research experience including the presentation of results.

Certification Scheme for QT Proficiency: area (II)

Focus on engineering



B1 **B1 Utilisation**
Modify/apply a QT facet

B2 **B2 Investigation**
Analyse performance, improve QT

C1 **C1 Specialisation**
Conceptualise integrated QT systems

C2 **C2 Innovation**
Develop new QT facet

QT facet: core, component, system, application; HW/SW see info box

Proficiency area **(II) QT HW & SW engineering** focuses on practical engineering skills with related concepts such as systems integration and industrial realisation. Specialisation may focus on a specific QT facet, e.g., a qubit realisation, a quantum algorithmic approach, a quantum sensing technology, or a specific part of a quantum network setup.

The intermediate B levels typically focus on a specific component or application that is being adapted, tested, utilised or analysed. Related influences or quantum effects that may occur are already considered, as are performance criteria.

In contrast, advanced C levels consider the whole system, how components or applications fit together and can be combined to create new systems or enable new applications. This relies on expertise about requirements from other parts of the system or related systems, etc.

Reaching these levels requires practical experience. Examination may need expert assessment of practical tasks.

Related content: extract from the CFQT content map

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

A **"QT facet"** can be, for example,
- NV centers as a QT core,
- a quantum error correction algorithm,
- a quantum communication protocol,
- a quantum gravity sensor, or
- a software programme using a quantum computing subroutine.

More in the info box on the next page.

Topics for the subdomains available in the CFQT, DOI 10.5281/zenodo.6834598, p. 8–12

Objectives for level B1 in (II) QT HW & SW engineering

B1 Utilisation: Modify/apply a QT facet
K: Knowledge of a variety of parts for QT facets and their influence (e.g. which quantum effects may occur and have some influence) on other (classical or hybrid) parts/systems and QT facets; specialised knowledge on a selected QT facet (hardware and/or software).
S: Ability to adapt and test QT facets, interpret and compare results.

Contents: Details on functionalities of QT facets from one or several QT domains (5, 6, 7), including fundamentals of related hardware (4), hybrid systems and interfaces (4.7), as well as enabling technologies and laboratory techniques (3). For example: Trapped ions as qubits 4.3 or a quantum simulation algorithm 5.2. Perform modification, e.g. replace a software subroutine or a sensing unit. Overview of several QT applications and/or components, and the manner in which they may impact other components, and/or be impacted by other components, including also the classical parts of the QT systems, specialisation on a selected application/component.

Qualifying works for proficiency verification

Short research project with documentation, e.g.
1. *Modify a QT facet:* e.g., modify a HW setup to solve an abstract problem in the lab.
2. *Implement a quantum algorithm:* Implement an algorithm or replace a computing subroutine to solve an abstract model problem.
3. *Interpret the result:* e.g., measurement result or algorithm output.
4. *Test a QT facet:* For a given HW setup or a software programme, test a variety of settings and compare the observations/results to the expectations.

Perform practical tasks, similar to what was learned from an instructor, but with some modifications/transfer. Examined by assessor, including correct and safe handling of HW and/or data.

Objectives for level B2 in (II) QT HW & SW engineering

B2 Investigation: Analyse performance, improve QT
K: Advanced knowledge in the context of a QT facet, including standards, requirements/performance criteria and aspects of technology realisation (turn into product).
S: Ability to analyse the adaptation or integration of a QT facet in order to improve it.

Contents: Similar as in B1 for more complex problems plus analysis, interpretation and documentation in the context of standards, benchmarking, requirements and industrialisation (4.8) .

Qualifying works for proficiency verification

For a modification of a QT facet: e.g., the modification of a HW setup or an algorithm for a concrete use case, or the replacement of a component:
1. Analyse the effect of the modification: e.g., compare the performance based on specific criteria or standards.
2. Examine the fit to requirements: e.g., verify compliance with requirements for systems integration.
3. Compare and select: Compare multiple modifications and select the best fit to the requirements.
4. Draw conclusions: Based on the changes made, formulate a proposal for further steps.

Primarily autonomous performance of the modification and analysis with documentation/reporting of the analysis.

Info box: QT facet

A **QT facet** can be – together with the underlying basics 5.1, 6.1, 7.1 – e.g.:
- [core] a QT core, e.g. a physical qubit realisation, see subdomains 4.1 to 4.5, or a quantum programming language 5.3;
- [component] a component around the QT core, e.g. a single photon detector, control software, an error correction algorithm, a user interface, see 3, 4.6 to 4.8, 5.3, 5.4;
- [system] a QT system, e.g. a quantum gravity sensor, quantum processor or quantum algorithm, see 5.2, 5.5, 6.2 to 6.6, 7.2, 7.3, 7.5;
- [application] a full application, i.e. an integrated system, e.g. a navigation system using a quantum gravity sensor or a full software program for simulating chemical processes using quantum-enhanced methods and running partly on a quantum device, see 5.6, 6.7, 7.4, 7.6.

from the CFQT, p. 16

Objectives for level C1 in (II) QT HW & SW engineering

C1 Specialisation: Conceptualise integrated QT systems
K: Highly specialised knowledge of one QT facet and critical awareness of connections between different QT facets and classical systems; methods of integration, also for hybrid quantum systems.
S: Ability to refine or extend systems, combine and integrate a quantum core and different components into a (hybrid) system/application (hardware and/or software), supervise QT manufacturing.

Contents: Specialisation on one QT system with the involved components (hardware and/or software), integration and systems engineering methods.

Qualifying works for proficiency verification

1. *Plan modification:* Plan modifications as in the B1 levels based on a critical assessment of the opportunities considering the full system.
2. *Plan integration:* Evaluate different opportunities to assess and select quantum and classical components to integrate into a system considering the full system, e.g. hardware and control software, or a full algorithm with classical and quantum parts, programming language, etc.
3. *Assess the pros and cons* for quantum-related components or for classical vs. quantum components.

Document the selection process including justification of decisions, e.g. in a project report or also a master thesis.

Objectives for level C2 in (II) QT HW & SW engineering

C2 Innovation: Develop new QT facet
K: State-of-the-art knowledge of a QT facet and its connections with various other QT facets.
S: Ability to develop innovative QT facet (core, system or application), evaluate and assess solutions, push the boundaries of current technology (thus, conduct research).

Contents: Expertise relevant for (industrial) research and development, including aspects relevant for the technological realisation (4.8), such as miniaturisation and scaling.

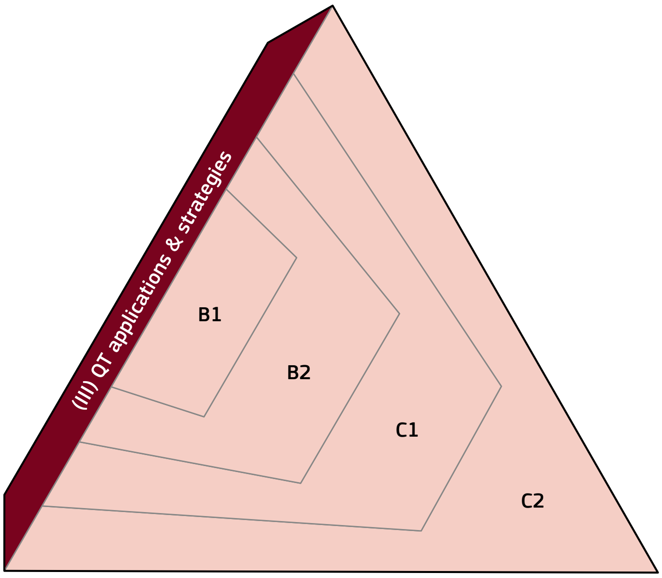
Qualifying works for proficiency verification

1. *Design a new device:* e.g. a quantum-enhanced magnetometer or a new quantum memory.
2. *Develop software:* e.g. a new quantum programming tool (such as a compiler).
3. *Evaluate and assess a new system/application:* For a new development, evaluate the technological advancements, analyse approaches and opportunities and limitations for technological realisation.

Document the work, e.g., in a research report or a scientific paper, take responsibility for the own research and developments.

Certification Scheme for QT Proficiency: area (III)

Focus on business and use cases



B1 — **B1 Utilisation**
Classify available QT applications/approaches

B2 — **B2 Investigation**
Analyse QT market and opportunities

C1 — **C1 Specialisation**
Advise on QT appl. selection or strategies

C2 — **C2 Innovation**
Develop and **assess** QT (product) strategies

Proficiency area **(III) QT applications & strategies** focuses on the business perspective and how to create value with QT. It covers business skills, such as market analysis and strategy assessment, in the context of QT. This requires a critical perspective on the potential and risks of QT in order to make a realistic assessment, taking into account not only the industrial impact but also, for example, the societal and environmental impact.

The focus may be on applications for a QT system or group of related QT systems, e.g. a company's products, and the ability to identify which product is best suited for which application, to analyse competitive products and to develop strategies for future products.

Another focus can be on a field of application where QT can be used with advantage. Here a competitive analysis can include quantum and classical (potential) solutions to a problem in the field of application. This would require expertise in the field of application and in classical solutions.

In addition, education and communication are covered in this proficiency area. Related competences include using QT to convey quantum concepts, taking into account common misconceptions, explaining an approach to the general public, or workforce development, such as analysing available training opportunities and identifying which employee should attend which programme. This is elaborated on the following pages as **Alternative** *QT in education and communication.*

Achieving such proficiency requires collaboration and engagement with the community, experts, market trends and developments, and keeping up to date with new developments. Formalised assessment is unusual, but experts could assess whether an individual has reached a particular level based on the illustrations on the following pages.

Related content: extract from the CFQT content map

QT systems and applications

5 QUANTUM COMPUTING AND SIMULATION
- 5.6 Applications of quantum computing and simulation

6 QUANTUM SENSORS AND IMAGING SYSTEMS
- 6.7 Applications of quantum sensors

7 QUANTUM COMMUNICATION AND NETWORKS
- 7.4 Applications of quantum cryptography
- 7.6 Systems networks (composite systems), quantum internet applications

8 VALORISATION
- 8.1 Industry landscape and market analysis
- 8.2 Business strategy, entrepreneurship and management
- 8.3 Impact and responsibility
- 8.4 Education and communitcation

Topics for the subdomains available in the CFQT, DOI 10.5281/zenodo.6834598, p. 10–13

Objectives for level B1 in (III) QT applications & strategies

B1 Utilisation: Classify available QT applications/approaches
K: Knowledge of a variety of (potential) applications/approaches with (dis)advantages and related providers and experts, specialised knowledge on a selected QT application on a field of application.
S: Ability to compare and select an application/approach for a specific problem/scenario.

Contents: Specialisation on a selected application (area) (a selected (sub)topic from 5.6, 6.7, 7.4, 7.6), with background on the application (quantum physics or engineering) and/or the field of application (e.g., medicine, finance, …). Focus on the industrial landscape, including aspects from market analysis (8.1), e.g. to select a specific QT product for (a company's) concrete circumstances.

Alternative *QT in education and communication* (8.4): Focus on existing materials and best practices on how to speak about quantum effects or how to use QT contexts to convey quantum concepts, e.g., to select an upskilling programme for an employee.

Qualifying works for proficiency verification

Choose an application: For a specific situation, e.g. a specific use case of a customer (in sales) or within the own company (as an end user), compare a limited number of options and select the best fit, explain the selection.

Example scenarios:

1. *(computing)* Choose a quantum computing (hardware) provider: For a quantum computing end-user company, such as a logistics company that wants to use quantum computing for optimisation problems, compare the quantum computing solutions available on the market with their cloud access options. Select the option that best meets the company's requirements, e.g. is suitable for solving the problems they want to solve, taking into account hardware benchmarks, usability and accessibility, as well as aspects such as pricing, data security, etc.

   (Requires expertise in the field of application, in this example optimisation problems in logistics and approaches to solve them.)
2. *(sensing)* Choose a quantum sensing approach for a use case: For a specific use case, e.g. a ground survey, select the appropriate sensing approach, e.g., a quantum gravimeter, and suggest a product/provider.

   (Requires overview of both, the quantum sensing approaches and the requirements in the field of application, e.g., in consulting.)
3. *(communication)* Choose a quantum cryptography approach from the company portfolio: For the situation of a customer, select the most suitable approach from the portfolio of the own company.

   (Requires expertise on the available solutions within the own company, e.g., as a sales/customer engineer.)

For examination, the quality of the selection process needs to be assessed by an expert.

Objectives for level B2 in (III) QT applications & strategies

B2 Investigation: Analyse QT market and opportunities
K: Advanced knowledge of a QT application and the related industry landscape and business models, including critical awareness on risks and potential consequences.
S: Ability to identify promising QT use cases with advances and risks, relate strategic QT reports to own business.

Contents: As level B1.
Focus on competitive analysis, benchmarking, etc. (from business strategy … 8.2), including also the review of strategic reports focusing on potential advances and risks of QT.

Alternative *QT in education and communication* (8.4): Analysis of existing materials considering advances and risks of the approaches to teach or speak about QT, including review of QT education research results, e.g., identify upskilling needs and review courses and other upskilling offers with a critical analysis of the seriousness and reliability of the provider.

Qualifying works for proficiency verification

Document an analysis: For a concrete (potential) QT use case or product, conduct a critical analysis of the available or currently developed opportunities, covering potential advances, risks, competitive analysis, …, e.g., to weigh up QT against available classical solutions.

Example scenarios:

1. *(computing)* For a concrete optimisation problem, analyse opportunities in quantum computing and classical alternatives, including a review of strategic reports to consider if to act now or wait for further technological readiness.
2. *(sensing)* For a quantum sensing product, e.g. an imaging device intended for medical use, analyse the market and potential customers also from other sectors, including a risk analysis of potential misuse of the product in other sectors.
3. *(communication)* For building up a quantum network, analyse the available infrastructure and the providers of commercial products with a critical review of the reports and roadmaps of the providers.

Objectives for level C1 in (III) QT applications & strategies

C1 Specialisation: Advise on QT application selection or strategies
K: Highly specialised knowledge in a field of application for a QT application incl. market situation etc., critical awareness of technologies and applications for a variety of application fields, including critical and ethical perspectives, impact assessment.
S: Ability to advise/assist companies in developing QT strategies and realising QT projects (investment or education), analyse and select available (technology/software) building blocks for integration.

Contents: As B levels: Specialisation on an application (field), i.e. a selected (sub)topic from 5.6, 6.7, 7.4, 7.6. Strong background in the field of application, e.g. finance or pharma looking at quantum computing, with available classical solutions and considering impact and ethical consequences 8.3, to make suggestions where to invest, what to buy, or what to integrate into a hardware system or a software programme.

Alternative *QT in education and communication* (8.4): Combine expertise in QT educational opportunities with a strong background in company-internal education and workforce dvelopment to make suggestions of where and how to upskill on a larger scale.

Qualifying works for proficiency verification

1. *Analysis of a specific situation of a customer:* use case, situation and resources of the customer, market with products and providers (including e.g. benchmarking).
2. *Identify and verify market gaps.*
3. *Evaluate investment opportunities in QT.*
4. *Prioritise projects* or actions, recommend next steps.

Always including assessment of impact and ethical consequences; with documentation and conclusion of a proposal, e.g. in a strategic report. Justify the decision, defend the results, take responsibility for the consequences.

Objectives for level C2 in (III) QT applications & strategies

C2 Innovation: Develop and assess QT (product) strategies
K: State-of-the-art knowledge in a field of application for a QT application incl. market situation etc. and how it relates to different approaches.
S: Ability to develop or evaluate/assess strategies/roadmaps for the development of quantum (enhanced) applications (HW/SW products) or curricula.

Contents: As level C1.
Focus on the business-related subdomain 8.2, e.g. product and service innovation, to create ideas and make assessment what product to develop, what market or end user sector to address.

Alternative *QT in education and communication* (8.4): Expertise to develop new educational programmes such as a new curriculum, develop or assess educational project proposals.

Qualifying works for proficiency verification

1. *Evaluate quality and reach of product,* e.g., of a new optimisation software including a (hidden) quantum algorithm subroutine.
2. *Develop a project idea and write a proposal,* e.g., of a new sensing device in medicine.
3. *Assess a project application.*
4. *Design or revise a technology/product roadmap,* e.g., for a quantum repeater hardware in the context of a quantum network.

Always including critical assessment (as in level C1) and with documentation/proposal preparation, negotiation, revision and defence of strategies, taking responsibility.