# Programme-specific Section of the Curriculum for the MSc Programme in

Quantum Information Science

# at the Faculty of Science, University of Copenhagen

2023 (rev. 2024)

## Contents

# 1 Title, affiliation and language

A shared section that applies to all BSc, part-time MSc and MSc Programmes at the Faculty of Science is linked to this programme-specific curriculum.

## 1.1 Title

The MSc Programme in Quantum Information Science leads to a Master of Science (MSc) in Quantum Information Science with the Danish title: *Cand.scient. (candidatus/candidata scientiarum) i kvanteinformationsvidenskab*.

## 1.2 Affiliation

The programme is affiliated with the Study Board of Mathematics and Computer Science, and the students can both elect, and be elected, to this study board.

## 1.3 Corps of external examiners

The following corps of external examiners is used for the central parts of the MSc Programme:

- Corps of External Examiners for Physics *(fysik)*.

## 1.4 Language

The language of this MSc Programme is English.

# 2 Academic profile

## 2.1 Purpose

The purpose is to educate MSc students in Quantum Information Science in the intersection between mathematics, physics and computer science who will obtain both theoretical, technological and experimental competences.

## 2.2 General programme profile

Quantum information theory, quantum technology, quantum computing, quantum algorithms, quantum simulations, secure encryption and communications are key subject areas of the programme.

## 2.3 General structure of the programme

The MSc Programme is set at 120 ECTS.

There are no defined specialisations in this programme.

## 2.4 Career opportunities

The MSc Programme in Quantum Information Science qualifies students to become professionals within business functions and/or areas such as:

- Development of new quantum algorithms to optimize complex calculations
- Development of systems and components for quantum information processing
- Consultant in companies and industry, for instance in connection with the development and implementation of quantum simulations
- Within the pharmaceutical industry, for instance to simulate experiments when developing medicines
- In telecommunications and banking to contribute to secure encryption and communications
- Start-ups within quantum information technology
- Research within quantum information science

# 3 Description of competence profiles

Students following the MSc Programme acquire the knowledge, skills and competences listed below. Students will also acquire other qualifications through elective subject elements and other study activities.

## 3.1 Competence profile

Graduates holding an MSc in Quantum Information Science have acquired the following:

Knowledge about:

- Key theoretical disciplines, principles, methods and concepts in quantum information science.
- Relevant interdisciplinary research-active fields within mathematics, physics and computer science.
- Technological methods in quantum information science experiments.
- Methods in quantum computing including protocols, applications, and algorithms.
- Literature, terminology, and research methods within quantum information science.
- Understanding of the interaction between quantum information science, mathematics, physics and computer science.

Skills in/to:

- Read and understand quantum information science original research literature.
- Account orally and in writing for inquiries into open quantum information science issues.
- Transforming quantum theory into quantum technology or quantum algorithms.
- Understand the basic setup of experiments in quantum information science.
- Assess potentials in technological and algorithmic quantum developments.
- Select, combine, and where appropriate develop or refine theories and methods, and use these to make a significant contribution to solving quantum information science problems or to promote a scientific understanding of the problems.
- Evaluate a proposed solution to a problem within quantum information objectively and systematically, and – where appropriate involving experiments – analyse the areas in which the solution is successful and unsuccessful, and identify its weaknesses, strengths and consequences.
- Communicate quantum information science and technology issues on a scientific basis.
- Documenting own research results and discoveries in a manner that meets the requirements for academic publications.

Competences in/to:

- Use and combine mathematics, physics and computer science to develop quantum information solutions.
- Master elements of multiple disciplines in particular mathematics, physics and computer science and being well versed in the methodology of quantum information science.
- Apply scientific theory and methodology in context of quantum information science.
- Acquire a comprehensive overview of complex scientific contexts, identify and analyse the computational or information-processing problems arising in such contexts, and decompose or transform the problems into a form amenable to solution by relevant quantum information science methodology.
- Acquire hands-on experimental experience with building blocks of quantum information processing.
- Work with others, both by playing an active role within research teams and/or industry by working closely with fellow students.

# 4 Admission requirements

## 4.1 Bachelor's degrees that automatically fulfil the academic requirements

Applicants with one of the following Bachelor's degrees automatically fulfil the academic requirements for admission to the MSc Programme in Quantum Information Science:

- Mathematics (*matematik*), Physics (*fysik*), Computer Science (*datalogi*) or Machine Learning and Data Science (*machine learning og datavidenskab*) from University of Copenhagen
- Mathematics, Physics or Computer Science from University of Southern Denmark
- Mathematics, Physics or Computer Science from Aarhus University
- Mathematics, Physics or Computer Science from Aalborg University
- Cyber Technology, Physics, Nanotechnology, Artificial Intelligence and Data, Mathematics and Technology or Software Technology from Technical University of Denmark
- Data Science from IT University of Copenhagen

## 4.2 Other Bachelor's degrees

Applicants with a Bachelor's degree, Professional Bachelor's degree or equivalent from Danish or international universities other than those listed in 4.1 are qualified for admission the MSc Programme in Quantum Information Science if the programme includes the following:

- A minimum of 120 ECTS within mathematics, physics and/or computer science

## 4.3 Other applicants

The Faculty may also admit applicants who, after an individual academic assessment, are assessed to possess educational qualifications equivalent to those required in Subclauses 4.1-2.

## 4.4 Language requirements

Applicants must as a minimum document English language qualifications comparable to a Danish upper secondary school English B level or English proficiency corresponding to the tests and scores required. Accepted tests and required minimum scores are published online at www.science.ku.dk.

## 4.5 Supplementary subject elements

The qualifications of an applicant to the MSc programme are assessed exclusively on the basis of the qualifying Bachelor's degree. Supplementary subject elements passed between the completion of the Bachelor's programme and the admission to the MSc programme cannot be included in the overall assessment.

However, subject elements passed before the completion of the Bachelor's programme may be included in the overall assessment. This includes subject elements completed as continuing education as well as subject elements completed as part of a former higher education programme. A maximum of 30 ECTS supplementary subject elements can be included in the overall assessment.

Subject elements passed before completing the Bachelor's programme which are to form part of the MSc programme to which the student has a legal right of admission (§15-courses) cannot be included in the overall assessment.

# 5 Prioritisation of applicants

There is no Bachelor's Programme with reserved access for this programme.

If the number of qualified applicants to the programme exceeds the number of places available, applicants will be prioritised according to the following criteria:

- Total number of ECTS within the relevant academic fields mathematics, physics and computer science
- Grades in courses within the relevant academic fields mathematics, physics and computer science.

# 6 Structure of the programme

The compulsory subject elements, restricted elective subject elements and the thesis constitute the central parts of the programme (Section 30 of the Ministerial Order on Bachelor and Master's Programmes (Candidatus) at Universities).

## 6.1 Programme components

The programme is set at 120 ECTS and consists of the following:

- Compulsory subject elements, 20 ECTS.
- Restricted elective subject elements
  - 40 ECTS (thesis, 30 ECTS)
  - 25 ECTS (thesis, 45 ECTS)
- Elective subject elements, 30 ECTS
- Thesis, 30 or 45 ECTS.

### *6.1.1 Compulsory subject elements*

| All of the following subject elements are to be covered (20 ECTS): | | | |
|---|---|---|---|
| **Course Code** | **Course Title** | **Block** | **ECTS** |
| NFYK23002U | Introduction to Quantum Information Science | Block 1 | 7.5 ECTS |
| NMAK23007U | Introduction to Quantum Computing | Block 1 | 7.5 ECTS |
| DTU: 10385 | Quantum Information Technology | Spring | 5 ECTS |

### *6.1.2 Restricted elective subject elements*

40 ECTS are to be covered as subject elements from the following list (thesis 30 ECTS):
25 ECTS are to be covered as subject elements from the following list (thesis 45 ECTS):

| 7.5 ECTS are to be covered as subject elements from the following list (thesis 30 or 45 ECTS): | | | |
|---|---|---|---|
| **Course Code** | **Course Title** | **Block** | **ECTS** |
| NMAK14020U | Quantum Information Theory | Block 2 | 7.5 ECTS |
| NFYK23005U | Physical Implementations of Quantum Information Processing | Block 2 | 7.5 ECTS |

| 10 ECTS are to be covered as subject elements from the following list (thesis 30 or 45 ECTS): | | | |
|---|---|---|---|
| **Course Code** | **Course Title** | **Block** | **ECTS** |
| DTU: 10386 | Experimental Techniques in Quantum Technology | June | 5 ECTS |
| DTU: 02196 | Quantum Compilers | Spring | 5 ECTS |
| DTU: 02195 | Quantum Algorithms and Machine Learning | Spring | 5 ECTS |

| 22.5 ECTS are to be covered as subject elements from the following list (thesis 30 ECTS):<br>7.5 ECTS are to be covered as subject elements from the following list (thesis 45 ECTS): | | | |
|---|---|---|---|
| **Course Code** | **Course Title** | **Block** | **ECTS** |
| NFYK15003U | Advanced Quantum Mechanics (Quant3)* | Block 1 | 7.5 ECTS |

| 22.5 ECTS are to be covered as subject elements from the following list (thesis 30 ECTS):<br>7.5 ECTS are to be covered as subject elements from the following list (thesis 45 ECTS): | | | |
|---|---|---|---|
| NDAK22000U | Machine Learning A | Block 1 | 7.5 ECTS |
| NDAA09023U | Advanced Algorithms and Data Structures | Block 2 | 7.5 ECTS |
| NMAK22000U | Analysis in Quantum Information Theory (AnQIT) | Block 2 | 7.5 ECTS |
| NFYK15007U | Condensed Matter Experiments | Block 2 | 7.5 ECTS |
| NFYK10017U | Condensed Matter Theory 1 (CMT1) | Block 2 | 7.5 ECTS |
| NMAK10008U | Functional Analysis | Block 2 | 7.5 ECTS |
| NFYK23005U | Physical Implementation of Quantum Information Processing | Block 2 | 7.5 ECTS |
| NMAK14020U | Quantum Information Theory | Block 2 | 7.5 ECTS |
| NDAK22001U | Machine Learning B | Block 4 | 7.5 ECTS |
| DTU: 10112 | Advanced Quantum Mechanics* | Autumn | 10 ECTS |
| DTU: 34042 | Quantum Photonic Communication (Kvantefotonisk kommunikation) | Autumn | 5 ECTS |
| DTU: 10302 | Electronic Structure Methods in Material Physics, Chemistry and Biology | Spring | 10 ECTS |
| DTU: 01227 | Graph Theory | Spring | 5 ECTS |
| DTU: 02180 | Introduction to Artificial Intelligence | Spring | 5 ECTS |
| DTU: 02233 | Network Security | Spring | 5 ECTS |
| DTU: 02195 | Quantum Algorithms and Machine Learning | Spring | 5 ECTS |
| DTU: 02196 | Quantum Compilers | Spring | 5 ECTS |
| DTU: 10380 | Quantum Optics | Spring | 10 ECTS |
| DTU: 10386 | Experimental Techniques in Quantum Technology | June | 5 ECTS |
| | Project in practice | Block 1-5 | Up to 15 ECTS |

*Only one of the courses can be included in the programme

### *6.1.3 Elective subject elements*

30 ECTS are to be covered as elective subject elements.

- All subject elements at MSc level may be included as elective subject elements in the MSc Programme.
- BSc subject elements corresponding to 15 ECTS may be included in the MSc Programme.
- Projects. See 6.1.4 Projects.

### *6.1.4 Projects*

Projects outside the course scope, projects in practice and thesis preparation projects may not exceed 30 ECTS of the programme.

- Projects outside the course scope may be included in the elective section of the programme with up to 15 ECTS. The regulations are described in Appendix 5 to the shared section of the curriculum.
- Projects in practice may be included in the elective and/or restricted elective section of the programme with 15 ECTS. Projects in practice may be written as a combination of the restricted elective and elective section of the programme. Projects in practice may not exceed 15 ECTS in total of the programme. The regulations are described in Appendix 4 to the shared section of the curriculum.
- Thesis preparation projects may be included in the elective section of the programme with up to 15 ECTS. The regulations are described in Appendix 6 to the shared section of the curriculum.

#### *6.1.5 Thesis*

The MSc Programme in Quantum Information Science includes a thesis corresponding to 30 ECTS or 45 ECTS, as described in Appendix 2 to the shared curriculum. The thesis must be written within the academic scope of the programme.

The main supervisor must be employed at either the Faculty of Science at the University of Copenhagen or at Technical University of Denmark.

#### *6.1.6 Academic Mobility*

The curriculum makes it possible to follow subject elements outside the Faculty of Science.

The academic mobility for the MSc Programme in Quantum Information Science (thesis 30 ECTS) is placed in block 1 and 2 of the 2nd year.

Academic mobility requires that the student follows the rules and regulations regarding pre-approval and credit transfer.

In addition, the student has the possibility to arrange similar academic mobility in other parts of the programme.

## 7 Exemptions

In exceptional circumstances, the study board may grant exemptions from the rules in the curriculum specified solely by the Faculty of Science.

## 8 Commencement etc.

### 8.1 Validity

This subject specific section of the curriculum applies to all students enrolled in the programme – see however Appendix 2.

### 8.2 Transfer

Students enrolled on previous curricula may be transferred to the new one as per the applicable transfer regulations or according to an individual credit transfer by the study board.

### 8.3 Amendment

The curriculum may be amended once a year so that any changes come into effect at the beginning of the academic year. Amendments must be proposed by the study board and approved by the Dean.

Notifications about amendments that tighten the admission requirements for the programme will be published online at www.science.ku.dk one year before they come into effect.

If amendments are made to this curriculum, an interim arrangement may be added if necessary to allow students to complete their MSc Programme according to the amended curriculum.

## Appendix 1 The recommended academic progression

The table illustrates the recommended academic progression. The student is allowed to plan an alternative progression within the applicable rules.

**Table – MSc Programme in Quantum Information Science (thesis 45 ECTS)**

<table>
<tr><th></th><th>Block 1</th><th>Block 2</th><th>Block 3</th><th>Block 4</th></tr>
<tr><td rowspan="4">1st year</td><td rowspan="3">Introduction to Quantum Computing</td><td rowspan="3">Restricted elective</td><td colspan="2">Quantum Information Technology (DTU)</td></tr>
<tr><td colspan="2">Restricted elective (DTU)</td></tr>
<tr><td colspan="2">Restricted elective (DTU)</td></tr>
<tr><td>Introduction to Quantum Information Science</td><td>Restricted elective</td><td colspan="2">Elective (DTU)</td></tr>
<tr><td rowspan="2">2nd year</td><td>Elective</td><td colspan="3" rowspan="2">Thesis</td></tr>
<tr><td>Elective</td></tr>
</table>

**Table – MSc Programme in Quantum Information Science (thesis 30 ECTS)**

<table>
<tr><th></th><th>Block 1</th><th>Block 2</th><th>Block 3</th><th>Block 4</th></tr>
<tr><td rowspan="4">1st year</td><td rowspan="3">Introduction to Quantum Computing</td><td rowspan="3">Restricted elective</td><td colspan="2">Quantum Information Technology (DTU)</td></tr>
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<tr><td>Introduction to Quantum Information Science</td><td>Restricted elective</td><td colspan="2">Restricted elective</td></tr>
<tr><td rowspan="2">2nd year</td><td>Elective</td><td>Elective</td><td colspan="2" rowspan="2">Thesis</td></tr>
<tr><td>Elective</td><td>Elective</td></tr>
</table>

## Appendix 2 Interim arrangements

The Shared Section that applies to all BSc, part-time MSc and MSc Programmes at the Faculty of Science applies to all students.

There are currently no interim arrangements.

## Appendix 3 Description of objectives for the thesis

After completing the thesis, the student should have:

Knowledge about:

- How to identify scientific problems within the study programme's subject area.
- How to summarize a suitable combination of methodologies and theories based on international research for use in the work of problem formulation.
- How to discuss theories and models on the basis of an organized value system and with a high degree of independence.

Skills in/to:

- Apply and critically evaluate theories and methods including their applicability and limitations.
- Assess the extent to which the production and interpretation of findings/material depend on the chosen theory or method.
- Discuss academic issues arising from the thesis.
- Draw conclusions in a clear and academic manner in relation to the problem formulation.
- Discuss and communicate the academic and social significance, if any, of the thesis based on ethical principles.

If the thesis includes experimental content and own data production, the student will also be able to:

- Substantiate the idea of conducting experimenting in order to shed light on the topic as described in the problem formulation.
- Process data through a choice of academic analysis methods and present findings objectively and in a concise manner.
- Assess the credibility of own findings based on relevant data processing.

Competences in/to:

- Initiate and perform academic work in a research context.
- Solve complex problems and carry out development assignments in a professional context.