Quantum Engineering

Degrees Offered

- Graduate Certificate in Quantum Engineering
- Master of Science (Non-Thesis)
- Master of Science (Thesis)

Program Requirements

Quantum Engineering is an interdisciplinary program that seeks to equip students for careers in emerging technologies based on quantum entanglement. It encompasses a wide range of disciplines that include physics, materials science, computer science, and mathematics, and is necessarily a collaborative effort among many Mines departments. Two Master's degrees and one Graduate certificate are offered.

For both degrees and the graduate certificate, Quantum Engineering has two "tracks" as summarized below. The Quantum Engineering Hardware (QEH) track will focus on experimental techniques relevant to quantum technology, while the Quantum Engineering Software (QES) track will focus on theory, algorithms and simulation. Students must choose a track to complete the program, but they may take courses from both tracks provided they meet the prerequisite requirements.

Graduate Certificate Curriculum Requirements:
The certificate option consists of three of the four new courses, plus one additional elective chosen from the above list, for a total of 12 credits.

Graduate Certificate, Software Track

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>PHGN519</td>
<td>FUNDAMENTALS OF QUANTUM INFORMATION</td>
<td>3.0</td>
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<tr>
<td>CSCI581</td>
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<tr>
<td>PHGN545</td>
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<td>Elective</td>
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Graduate Certificate, Hardware Track

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<td>EENG/PHGN532</td>
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MS Degree Curriculum Requirements:

A Master of Science in Quantum Engineering will consist of 30 total credits. Students may choose a thesis or non-thesis option for this degree. For the thesis option, 9 credits out of the 30 are devoted to thesis research leading to an acceptable Master's thesis. Students choosing the non-thesis option will devote all 30 credits to coursework. Regardless of the option chosen, 9 of the coursework credits will be devoted to the required core classes for the chosen track.

Reflecting the interdisciplinary nature of the program, we strongly recommend to our students that at least 9 total credits of the MS degree coursework should come from courses in a department outside of the student's undergraduate major. The required core courses, if outside of the student's major, would count towards this recommendation. Our guiding philosophy is that the problem of building a quantum computer is a complex, interdisciplinary one which requires contributions from a vast array of subfields, and young scientists who appreciate this will likely have a far better perspective on the field than those who do not.

MS Non-Thesis Software Track

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MS Non-Thesis Hardware Track

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MS Thesis Software Track

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Coursework Details:

QES students will be required to take these courses in the following sequence:

In the Fall:

- PHGN519, Fundamentals of Quantum Information

In the Spring:
• CSCI581, Quantum Programming
• PHGN545, Quantum Many-Body Physics

QEH students will be required to take these courses in the following sequence:

In the Fall:
• PHGN519, Fundamentals of Quantum Information

In the Spring:
• PHGN435/PHGN535, Interdisciplinary Silicon Processing Laboratory
• PHGN532, Low Temperature Microwave Measurements for Quantum Applications

Approved Electives:

Physics Electives
PHGN440 SOLID STATE PHYSICS 3.0
PHGN441 SOLID STATE PHYSICS APPLICATIONS AND PHENOMENA 3.0
PHGN466/566 MODERN OPTICAL ENGINEERING 3.0
PHGN480 LASER PHYSICS 3.0
PHGN520 QUANTUM MECHANICS I 3.0
PHGN521 QUANTUM MECHANICS II 3.0
PHGN530 STATISTICAL MECHANICS 3.0
PHGN550 NANOSCALE PHYSICS AND TECHNOLOGY 3.0
PHGN585 NONLINEAR OPTICS 3.0

Computer Science Electives
CSCI542 SIMULATION 3.0
CSCI563 PARALLEL COMPUTING FOR SCIENTISTS AND ENGINEERS 3.0
CSCI564 ADVANCED COMPUTER ARCHITECTURE 3.0
CSCI571 ARTIFICIAL INTELLIGENCE 3.0
CSCI474 INTRODUCTION TO CRYPTOGRAPHY 3.0
CSCI575 ADVANCED MACHINE LEARNING 3.0
CSCI580 ADVANCED HIGH PERFORMANCE COMPUTING 3.0

Electrical Engineering Electives
EENG509 SPARSE SIGNAL PROCESSING 3.0
EENG417/517 MODERN CONTROL DESIGN 3.0
EENG526 ADVANCED ELECTROMAGNETICS 3.0
EENG528 COMPUTATIONAL ELECTROMAGNETICS 3.0
EENG529 ACTIVE RF & MICROWAVE DEVICES 3.0
EENG530 PASSIVE RF & MICROWAVE DEVICES 3.0
EENG617 INTELLIGENT CONTROL SYSTEMS 3.0
EENG618 NONLINEAR AND ADAPTIVE CONTROL 3.0

Metallurgy and Material Engineering Electives
MTGN456 ELECTRON MICROSCOPY 2.0
MTGN505 CRYSTALLOGRAPHY AND DIFFRACTION 3.0

Materials Science Electives
MLGN593 BONDING, STRUCTURE, AND CRYSTALLOGRAPHY 3.0

Applied Mathematics and Statistics Electives
MATH408 COMPUTATIONAL METHODS FOR DIFFERENTIAL EQUATIONS 3.0
MATH436 ADVANCED STATISTICAL MODELING 3.0
MATH438 STOCHASTIC MODELS 3.0
MATH510 ORDINARY DIFFERENTIAL EQUATIONS AND DYNAMICAL SYSTEMS 3.0
MATH551 COMPUTATIONAL LINEAR ALGEBRA 3.0

Humanities, Arts, and Social Sciences Electives
HASS423 ADVANCED SCIENCE COMMUNICATION 3.0

Mines’ Combined Undergraduate / Graduate Degree Program:
As with many other graduate programs, students enrolled in Mines’ combined undergraduate/graduate program may double count up to six credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their quantum engineering MS degree. Any 400+ level courses that count towards the undergraduate degree requirements as “Elective Coursework” or any 500+ level course, may be used for the purposes of double counting at the discretion of the graduate advisor. These courses must have been passed with a “B-” or better, not be substitutes for required coursework, and meet all other University, Department, Division, and Program requirements for graduate credit.

Program Director
Eliot Kapić, Associate Professor, Physics

Department of Applied Mathematics and Statistics
Cecilia Diniz Behn, Associate Professor

Department of Computer Science
Neil Dantam, Assistant Professor
Dinesh Mehta, Professor
Hua Wang, Associate Professor
Bo Wu, Associate Professor
Dejun Yang, Associate Professor
Hao Zhang, Associate Professor

Department of Electrical Engineering
Peter Aaen, Professor
Payam Nayeri, Assistant Professor

Department of Metallurgical and Materials Engineering
Geoff Brennecka, Associate Professor
Brian Gorman, Associate Professor
Andriy Zakutayev, Research Assistant Professor

Department of Physics
Lincoln Carr, Professor
Serena Eley, Assistant Professor
Zhexuan Gong, Assistant Professor
Eliot Kapit, Associate Professor
Kyle Leach, Associate Professor
Meenakshi Singh, Assistant Professor

**Affiliated Faculty**
Matt Beard, Joint Appointment, NREL and Chemistry
Justin Johnson, Joint Appointment, NREL and Physics
Adele Tamboli, Joint Appointment, NREL and Physics