

# Everything You Need for Experimental Quantum Hardware Engineering

University of Minnesota

Onri Jay Benally

July 2023

## Creative Commons License

This work is licensed under the Creative Commons Attribution 4.0 International License. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/> or send a letter to Creative Commons, PO Box 1866, Mountain View, CA 94042, USA.



# Contents

1	Open Access Quantum Device Tools	3
2	Training Videos	4
3	Books & References	6
4	Quantum Hardware Lab Galleries	8
5	Quantum-Applicable Degrees: BS to PhD	9
6	Quantum Science Curriculum Example	10
7	Quantum Career Opportunities	12

# Chapter 1

## Open Access Quantum Device Tools

Free tools for designing, simulating, & analyzing quantum/ nano devices:

- **Browser-based, no installation required:**  
<https://nanohub.org/groups/semiconductoreducation>
- **Browser-based, no installation required:**  
<https://nanohub.org/groups/education#LearnAbout>
- **COMSOL superconducting simulation tool, browser-based:**  
<https://aurora.epfl.ch/app-lib>
- **Multiphysics simulation tool, direct-download:**  
<https://www.csc.fi/web/elmer/binaries>
- **Qubit design/ simulation/ analysis, Python-based:**  
<https://docs.nanoacademic.com/qtcad/introduction>
- **Qubit design/ analysis, Python-based:**  
<https://github.com/qiskit-community/qiskit-metal#qiskit-metal>
- **Quantum optics, Python-based:**  
<https://github.com/fancompute/qpga#quantum-programmable-gate-arrays>
- **Quantum optics, Python-based:**  
<https://github.com/SiEPIC/SiEPIC-Tools#siepic-tools>
- **Qubit design & fabrication example, applies codes to run lithography machines in the lab after pattern generation with Qiskit:**  
<https://github.com/OJB-Quantum/Qiskit-Metal-to-Litho#qiskit-metal-to-litho>
- **GitHub usage tutorial:**  
<https://github.com/OJB-Quantum/How-to-GitHub#how-to-use-github>
- **Superconducting qubit simulation tool, Python-based:**  
<https://scqubits.readthedocs.io/en/v3.2/index.html>

# Chapter 2

## Training Videos

Related Open Access Lectures & Tutorials (Up to Graduate-Level):

- **Pulse Sequence Shaping (Thomas Alexander, IBM):**  
<https://www.youtube.com/watch?v=sMUPL8SR2oE&t=665s>
- **Qiskit Metal Overview, Gmsh & ElmerFEM [Open-Source] (Diego Emilio Serrano & Abeer Vaishnav):**  
[https://youtu.be/84j3l\\_9fHko](https://youtu.be/84j3l_9fHko)
- **Quantum Transport (Prof. Sergey Frolov):**  
[https://youtube.com/playlist?list=PLtTPtV8SRcxjedflXwNPSI\\_fxvxwUCjsd](https://youtube.com/playlist?list=PLtTPtV8SRcxjedflXwNPSI_fxvxwUCjsd)
- **Quantum Many-Body Physics (Prof. Luis Gregório Dias):**  
[https://youtube.com/playlist?list=PL6FyrZIBwD8LMWizZW1FUN2dS\\_144yuiy](https://youtube.com/playlist?list=PL6FyrZIBwD8LMWizZW1FUN2dS_144yuiy)
- **Quantum Matter (Prof. Steven Simon):**  
[https://youtube.com/playlist?list=PLrNpJ0aBSWScRLU0\\_tuKa5l5YJl0JNr1z](https://youtube.com/playlist?list=PLrNpJ0aBSWScRLU0_tuKa5l5YJl0JNr1z)
- **Quantum Computing Hardware & Architecture (Prof. Hiu Yung Wong):**  
<https://youtube.com/playlist?list=PLnK6MrIqGXsL1KShnocSdwNSiKnBodpie>
- **Quantum Hardware Series (Onri Jay Benally, QuantumGrad & UMN):**  
[https://youtube.com/playlist?list=PLD9iE8dbH\\_2W0ww1HL1gSskSYPCs1f6cd](https://youtube.com/playlist?list=PLD9iE8dbH_2W0ww1HL1gSskSYPCs1f6cd)
- **Circuit Quantum Electrodynamics & Qubit Hamiltonian (Prof. Gerhard Kirchmair):**  
<https://youtu.be/BAt2PFVQE3w>
- **Josephson Junctions & SQUIDs (Prof. Kevin F. Kelly):**  
<https://youtu.be/sN0pmTWlMwk>
- **Virtual Hands-On Nanofabrication (Dr. Jorg Scholvin):**  
<https://youtu.be/01J8qKjcp0M>
- **Micro & Nanofabrication (Prof. Chris Mack):**  
[https://youtube.com/playlist?list=PLM2eE\\_hI4gSDjK4SiDbhmpjw31Xyqfo](https://youtube.com/playlist?list=PLM2eE_hI4gSDjK4SiDbhmpjw31Xyqfo)

- **Nanotechnology [Tools] (Duke University):**  
<https://youtube.com/playlist?list=PLQcKpS4i0cAHES0sjJTXDZnWa3wtuixQl>
  
- **Physical Sciences & Engineering (Dr. Jordan Edmunds):**  
<https://www.youtube.com/@JordanEdmundsEECS/playlists>
  
- **Animated Physics Lectures (ZAP Physics):**  
<https://www.youtube.com/@zapphysics/playlists>
  
- **More Animated Physics Lectures (Alexander Fufaev):**  
<https://www.youtube.com/@universaldenker/playlists>
  
- **Even More Animated Physics Lectures (Dr. Elliot Schneider):**  
<https://www.youtube.com/@PhysicswithElliot/playlists>
  
- **Electronic Circuits (Julio Gonzalez):**  
[https://youtube.com/playlist?list=PL0o\\_zxa4K1BV9E-N8tSExU1djL6slnbL](https://youtube.com/playlist?list=PL0o_zxa4K1BV9E-N8tSExU1djL6slnbL)

# Chapter 3

## Books & References

Free or Open Access Literature & More (Up to Graduate-Level):

- **Olivier Ezratty's "Understanding Quantum Technologies" (research, manufacturing, & more):**  
<https://arxiv.org/abs/2111.15352>
- **Olivier Ezratty's "Where are we heading with NISQ?":**  
<https://arxiv.org/abs/2305.09518>
- **Computer-Inspired Quantum Experiments:**  
<https://arxiv.org/abs/2002.09970>
- **The Transmon Qubit for Electromagnetics Engineers:**  
<https://ieeexplore.ieee.org/document/9789946>
- **Thomas Wong's "Introduction to Classical & Quantum Computing":**  
<https://www.thomaswong.net/introduction-to-classical-and-quantum-computing-1e3p.pdf>
- **Probing quantum devices with radio-frequency reflectometry:**  
<https://arxiv.org/abs/2202.10516>
- **[Quantum] Transport in Semiconductor Mesoscopic Devices:**  
<https://iopscience.iop.org/book/mono/978-0-7503-1103-8/chapter/bk978-0-7503-1103-8ch8>
- **Quantum Materials Roadmap:**  
<https://iopscience.iop.org/article/10.1088/2515-7639/abb74e>
- **Quantum Nanostructures:**  
<https://www.sciencedirect.com/science/article/pii/B9780081019757000038>
- **From Nanoelectronics to Future Technologies:**  
[https://link.springer.com/chapter/10.1007/978-3-030-44398-6\\_6#Sec5](https://link.springer.com/chapter/10.1007/978-3-030-44398-6_6#Sec5)
- **A Practical Guide for Building Superconducting Quantum Devices:**  
<https://arxiv.org/pdf/2106.06173.pdf>

- **Handbook of Vacuum Science & Technology:**  
<https://www.sciencedirect.com/book/9780123520654/handbook-of-vacuum-science-and-technology>
- **Practical Cryogenics:**  
<http://research.physics.illinois.edu/bezryadin/links/practical%20Cryogenics.pdf>
- **Coplanar Waveguide Resonators:**  
<https://link.springer.com/article/10.1007/s10948-018-4959-2>
- **When to Use Coplanar Waveguide Routing:**  
<https://blog.upverter.com/2019/10/15/when-to-use-coplanar-waveguide-routing-for-hf-boards>
- **Control & Readout of a Superconducting Qubit Using a Photonic Link:**  
<https://rdcu.be/dhLr3>
- **Cryo-CMOS Qubit Control:**  
<https://ieeexplore.ieee.org/document/9895434>
- **The Electronic Interface for Quantum Processors:**  
<https://arxiv.org/pdf/1811.01693.pdf>
- **Cryo-CMOS Interfaces for Large-Scale Quantum Computers:**  
<https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9372075>
- **A Cryogenic Interface for Controlling Many Qubits:**  
<https://arxiv.org/abs/1912.01299>
- **Cryogenic Memory Technologies:**  
<https://arxiv.org/abs/2111.09436>
- **NASA Wire Bonding Standards:**  
<https://nepp.nasa.gov/index.cfm/20911>
- **NASA Soldering & Workmanship Standards:**  
<https://nepp.nasa.gov/docuploads/06AA01BA-FC7E-4094-AE829CE371A7B05D/NASA-STD-8739.3.pdf>  
[https://standards.nasa.gov/sites/default/files/standards/NASA/A/4/nasa-std-87394a\\_w\\_change\\_4\\_0.pdf](https://standards.nasa.gov/sites/default/files/standards/NASA/A/4/nasa-std-87394a_w_change_4_0.pdf)  
<https://workmanship.nasa.gov/lib/insp/2%20books/frameset.html>
- **Semiconductor Process & Device Simulation (SILVACO, browser-based):**  
<https://nanohub.org/resources/silvacotcad>
- **Quantum Mechanics Visualization (browser-based):**  
<https://www.st-andrews.ac.uk/physics/quvis>
- **Classical Physics Simulation (browser-based):**  
<https://phet.colorado.edu/en/simulations/browse>
- **Classical 2D Optics Simulation (browser-based):**  
<https://phydemo.app/ray-optics>



## Chapter 4

### Quantum Hardware Lab Galleries

<b>IBM Research</b> <a href="https://www.flickr.com/photos/ibm_research_zurich/albums">https://www.flickr.com/ photos/ibm_research_ zurich/albums</a>	<b>ETH Zurich</b> <a href="https://qudev.phys.ethz.ch/responsive/?q=gallery">https://qudev.phys.ethz. ch/responsive/?q=gallery</a>

## Chapter 5

### Quantum-Applicable Degrees: BS to PhD

Non-Exhaustive List:	
Physics (Experimental or Applied)	Computer Engineering
Quantum Science & Engineering	Chemistry
Quantum Technology	Chemical Engineering
Engineering Physics	Physical Chemistry
Electrical Engineering	Systems Engineering
Electrical & Computer Engineering	Mechanical Engineering
Materials Science	Nanoscience
Materials Science & Engineering	



# Chapter 6

## Quantum Science Curriculum Example

Courses:		
AEP	1200	Introduction to Nanoscience & Nanoengineering
AEP	2550	Engineering Quantum Information Hardware
AEP	3100	Introductory Quantum Computing
AEP	3610	Introductory Quantum Mechanics
AEP	3620	Intermediate Quantum Mechanics
AEP	4400	Nonlinear & Quantum Optics
AEP	4500 / PHYS 4454	Introductory Solid State Physics
CHEM	7930	Quantum Mechanics I
CHEM	7870	Mathematical Methods of Physical Chemistry
CHEM	7910	Advanced Spectroscopy
CHEM	7930	Quantum Mechanics I
CHEME	6860 / SYSEN 5860	Quantum Computing & Artificial Intelligence
CS	4812 / PHYS 4481	Quantum Information Processing
ECE	4060	Quantum Physics & Engineering
ECE	4070	Physics of Semiconductors & Nanostructures
ECE	5310	Quantum Optics for Photonics & Optoelectronics
ECE	5330	Semiconductor Optoelectronics
MSE	5720	Computational Materials Science
MSE	6050	Physics of Semiconductors & Nanostructures
PHYS	2214	Physics III: Oscillations, Waves, & Quantum Physics
PHYS	3316	Basics of Quantum Mechanics
PHYS	3317	Applications of Quantum Mechanics
PHYS	4443	Intermediate Quantum Mechanics
PHYS	4444	Introduction to Particle Physics
PHYS	4410 / PHYS 6510	Advanced Experimental Physics
PHYS	6572	Quantum Mechanics I
PHYS	6574	Applications of Quantum Mechanics II
PHYS	7636	Solid-State Physics II
PHYS	7645	An Introduction to the Standard Model of Particle Physics
PHYS	7651	Relativistic Quantum Field Theory I
PHYS	7652	Relativistic Quantum Field Theory II
PHYS	7654	Basic Training in Condensed Matter Physics
Adapted From: <a href="https://quantum.cornell.edu/education">https://quantum.cornell.edu/education</a>		

# Chapter 7

## Quantum Career Opportunities

Quantum Job Resources (Hardware & Software):

- <https://www.youtube.com/watch?v=7dfw8k2p1to>
- <http://ibm.techtechpotato.com>
- <https://chicagoquantum.org/resources>
- <https://www.quantiki.org/jobs>
- <https://qubitjobs.com>
- <https://medium.com/@russfein/quantum-computing-jobs-5e67f72fb113>
- <https://quantumconsortium.org/quantum-jobs>
- <https://qhack.ai/job-board>
- <https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9733176>
- <https://www.globalquantumleap.org/quantum-opportunities-1>
- <https://chicagoquantum.org/education-and-training/internships>
- <https://www.quantumgrad.com>