Everything You Need for Experimental Quantum Hardware Engineering

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Contents

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 Metal):**
  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
- **Quantum Transport (Prof. Sergey Frolov):**
  https://youtube.com/playlist?list=PLtTPtV8SRcxjedflXwNPSI_fxvxwUCjsd
- **Quantum Many-Body Physics (Prof. Luis Gregório Dias):**
  https://youtube.com/playlist?list=PL6FyrZIBwD8LMWizZW1FUN2dS_l44yuiy
- **Quantum Matter (Prof. Steven Simon):**
  https://youtube.com/playlist?list=PLrNpJOaBSWSCrLUO_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_2W0ww1HL1gSskSYPcSlf6cd
- **Circuit Quantum Electrodynamics & Qubit Hamiltonian (Prof. Gerhard Kirchmair):**
  https://youtu.be/BAt2PFVQE3w
- **Josephson Junctions & SQUIDs (Prof. Kevin F. Kelly):**
  https://youtu.be/sNOpmTWlMwk
- **Virtual Hands-On Nanofabrication (Dr. Jorg Scholvin):**
  https://youtu.be/01J8qKjcp0M
- **Micro & Nanofabrication (Prof. Chris Mack):**
  https://youtube.com/playlist?list=PLM2eE_hI4gSDjK4SiDbhpmpjw31Xyqfo

- **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-N8tSExU1djL6slnjbL

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
- **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://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

IBM Research https://www.flickr.com/photos/ibm_research_zurich/albums	**ETH Zurich** https://qudev.phys.ethz.ch/responsive/?q=gallery

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: `https://quantum.cornell.edu/education`		

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