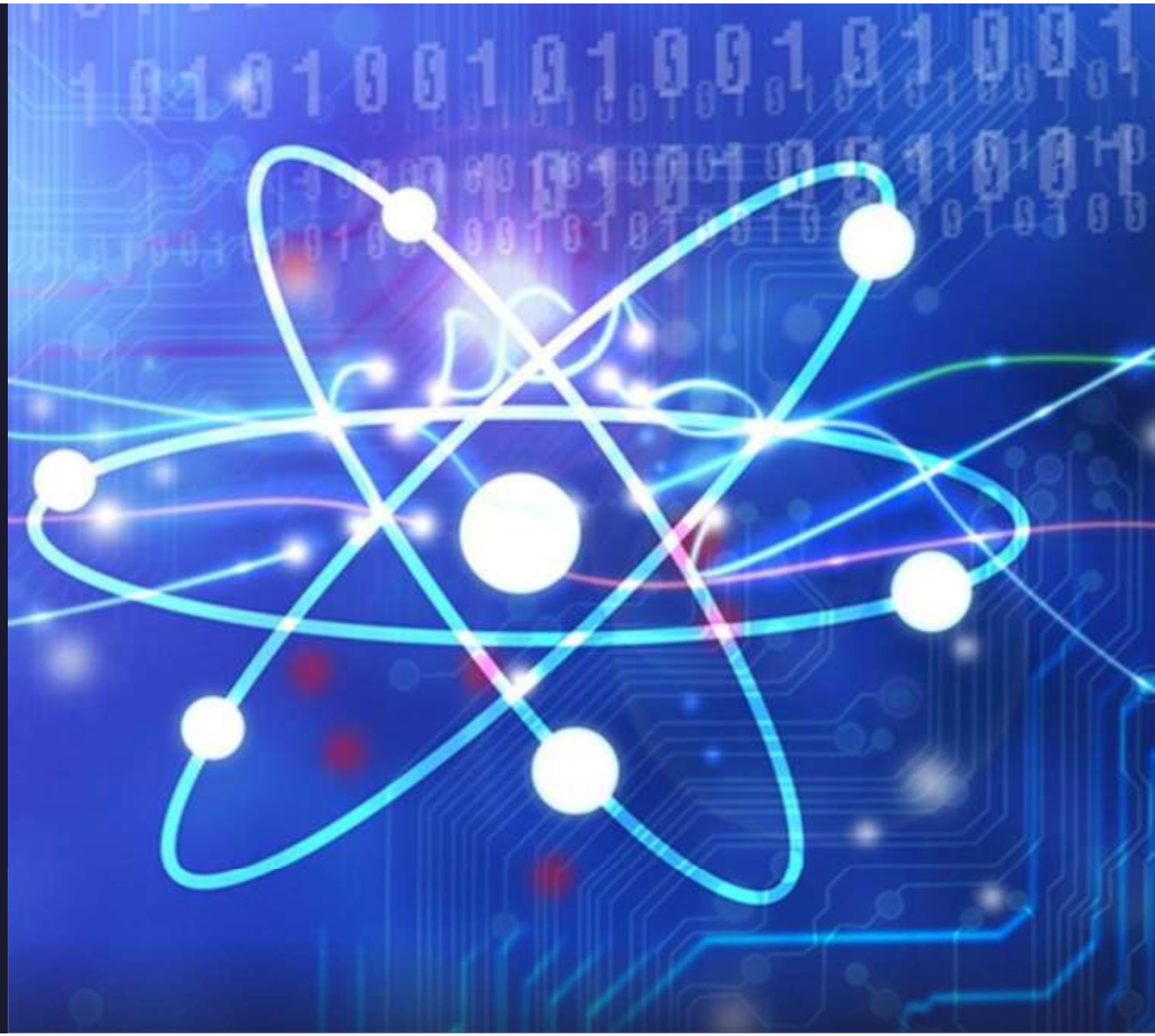
# Quantum for High School & College Students

**Education & Career Pathways**


## Donn Silberman

- Optics Institute of Southern California
- http://oisc.net

# Introduction

## Who am I?

And Why am I here talking to you?

- **QuantumOpticsAge –**
- **https://donn601.wixsite.com/opticsage**


The Optics Institute Of Southern California

PCC LASERTECH Pasadena City College

SPS Society of Physics Students


THE UNIVERSITY OF ARIZONA A | Physics

UA HONORS COLLEGE Founded 1962 50 years

COLLEGE OF OPTICAL SCIENCES
COLLEGE OF ENGINEERING

UCI Division of Continuing Education
Optical Engineering & Optical Instrument Design

SPIE. Fellow

OPTICA SENIOR MEMBER

OSSC Optical Society of Southern California
FELLOW

eLas Americas

OptoBotics℠
Robots need eyes too

# Critical Thinking




# Mentors

Frank Memmer

Ke Chiang Hsieh

William Bickel

Bob Fisher

Al Hatheway

Brian Lula

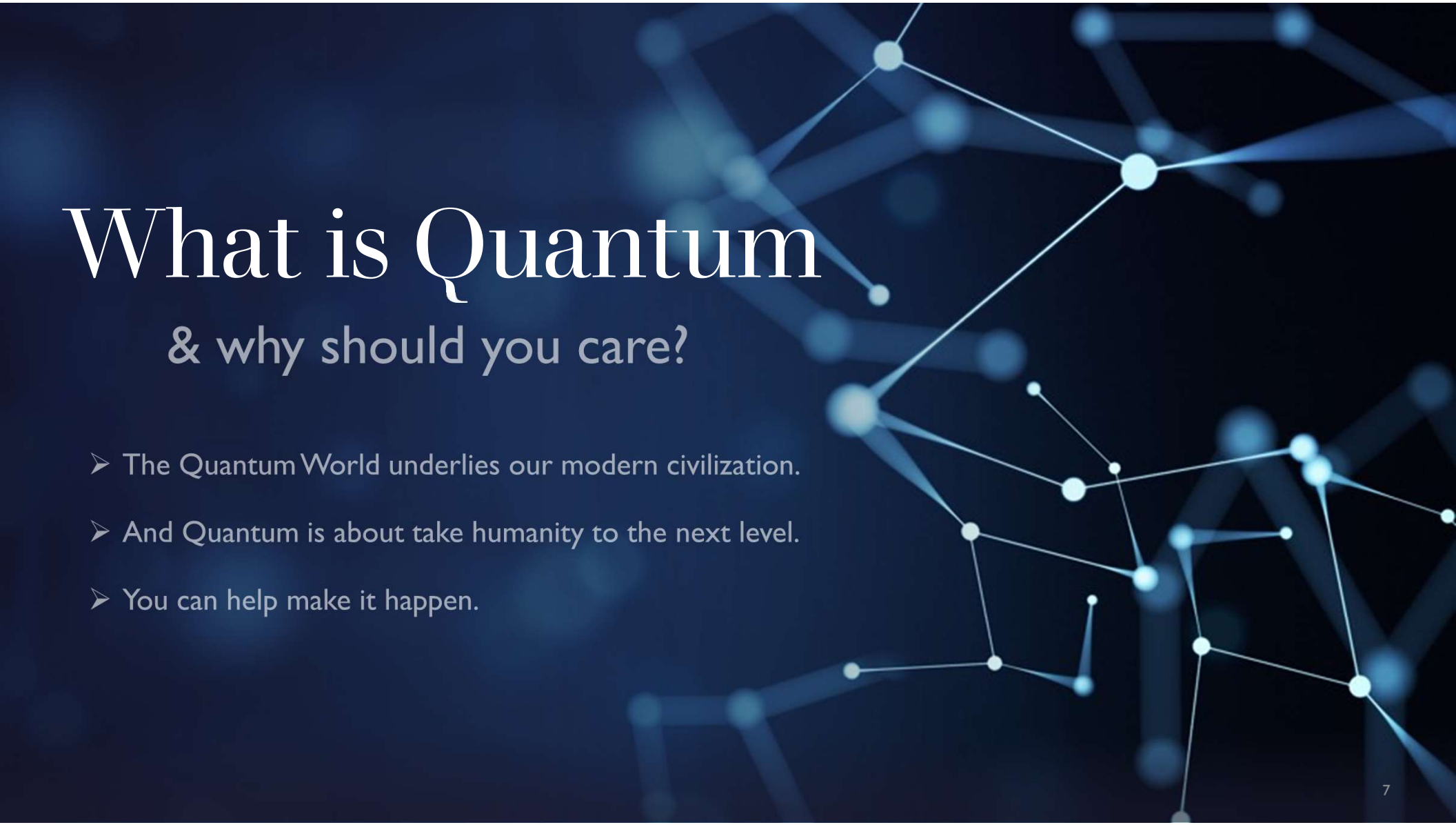
Jim Trolinger

**Steve Jacobs**
Univ. of Rochester
Optics Suitcase

My wife, Mom & Dad

# Agenda

1. What is Quantum & why should you care?
2. Quantum Computers & Cybersecurity
3. Many More Quantum Applications
4. Pathways for High School & College Students
5. On-line and In-Person Resources
6. Questions & Answers


What is Quantum
& why should you care?
The Quantum World underlies our modern civilization.
And Quantum is about take humanity to the next level.
You can help make it happen.

Article Landing Page | opticsage (donn601.wixsite.com)

This web page has the article below and links to all the references.

## Quantum Theory with Computer & Cyber Security Applications

Donn M. Silberman, Fellow of the OSSC & SPIE


Here are the first two paragraphs of the article. Click on the link below to download the full article.

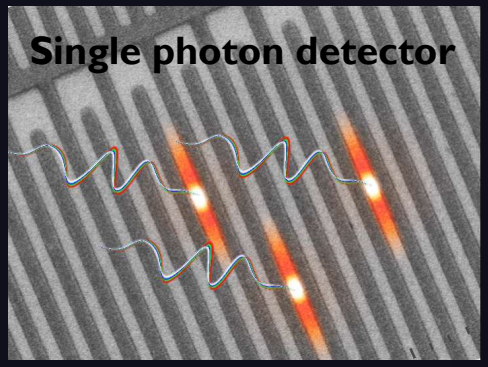
From Wikipedia: QUANTUM

In physics, a quantum is the minimum amount of any physical entity involved in an interaction. The fundamental notion that a physical property can be "quantized" is referred to as "the hypothesis of quantization".

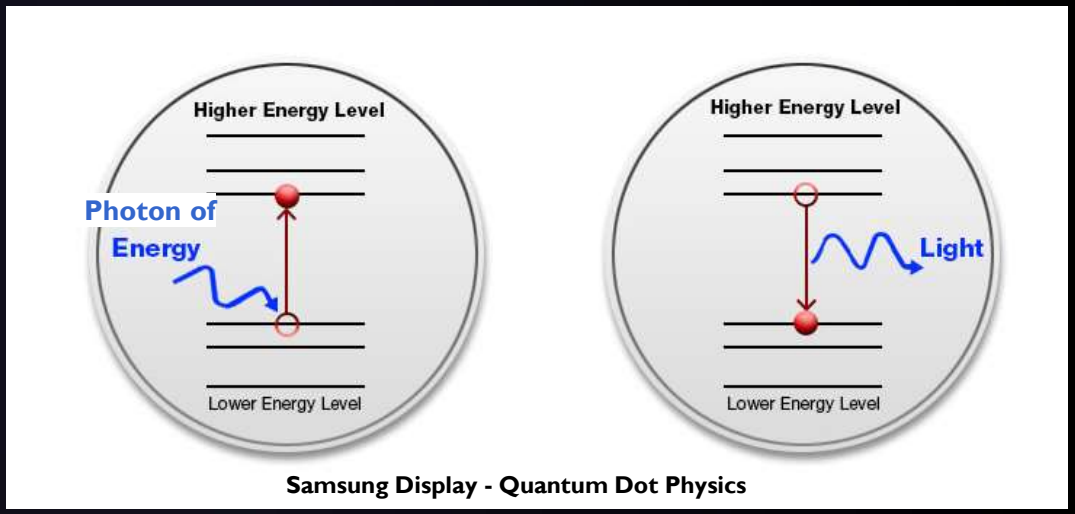
*[1] This means that the magnitude of the physical property can take on only* ***discrete values*** *consisting of integer multiples of one quantum.*

**Can't have 1 ½ photons**
**Or ¾ of an electron**

Graphic representation of an **electron (red O)** moving from one energy level to another, emitting or absorbing a **photon (Energy)** of light.

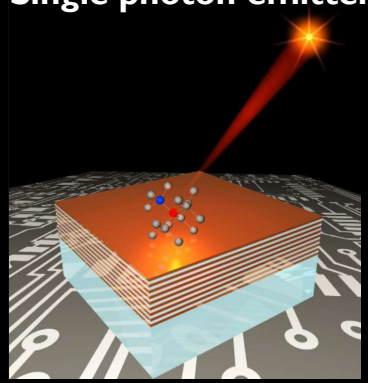



1-singlephoton.jpg (716×536) (b-cdn.net))




**Samsung Display - Quantum Dot Physics**

**Single photon emitter**



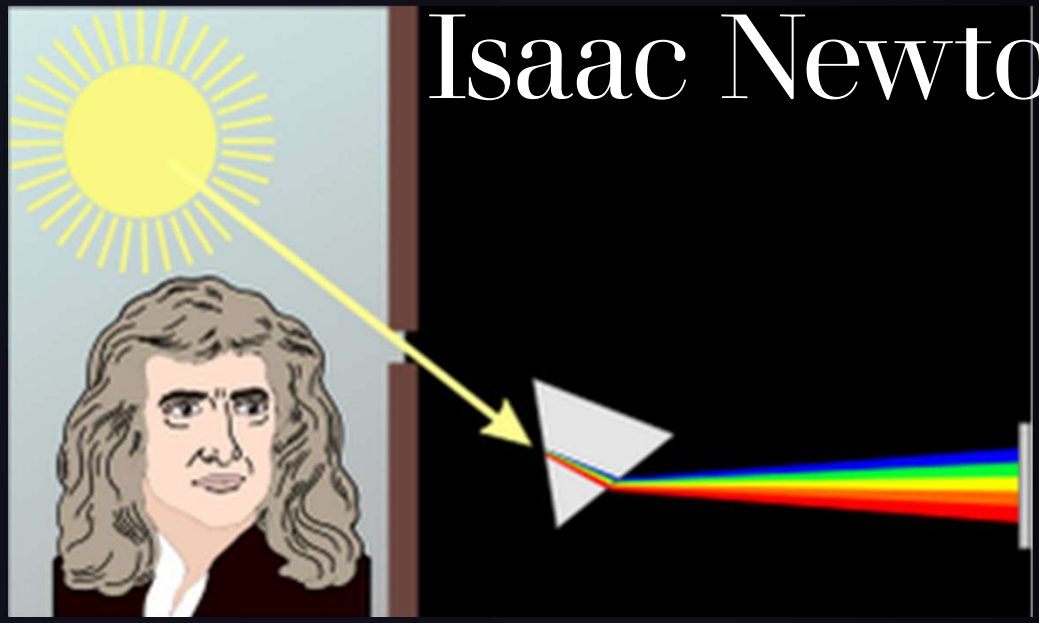
singlephoton.jpg (1000×1413) (b-cdn.net)

$E = h\nu$ — Quantum energy of a photon. ($\nu$: frequency of radiation, sometimes written as f giving expression E = hf.)

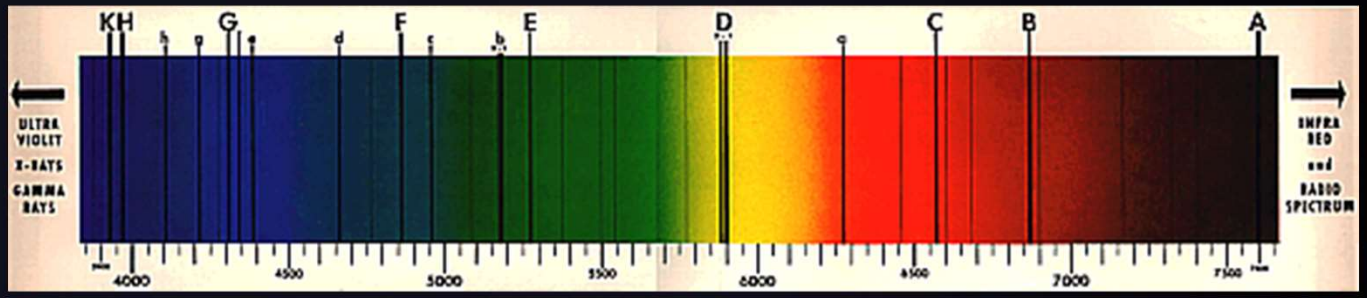
h = Planck's constant = $6.626 \times 10^{-34}$ Joule·sec = $4.136 \times 10^{-15}$ eV·s

$E=mc^2$

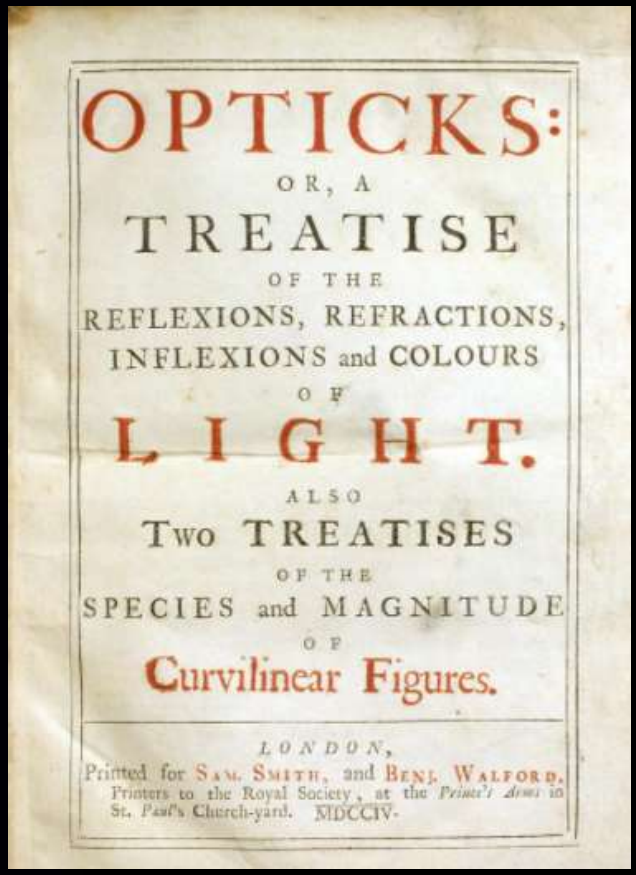
# Isaac Newton & the Prism



## The Solar Spectrum with Fraunhofer Lines




Discrete spectral lines correspond to the energy levels of various atoms that are burning in the Sun.



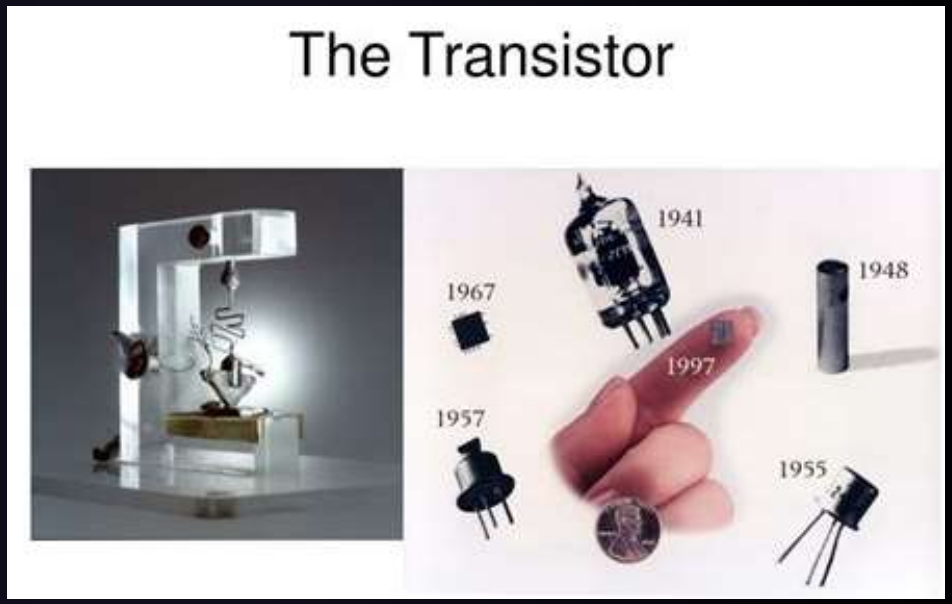
OPTICKS:
OR, A
TREATISE
OF THE
REFLEXIONS, REFRACTIONS,
INFLEXIONS and COLOURS
OF
LIGHT.
ALSO
Two TREATISES
OF THE
SPECIES and MAGNITUDE
OF
Curvilinear Figures.

LONDON,
Printed for Sam. Smith, and Benj. Walford,
Printers to the Royal Society, at the *Prince's Arms* in
St. *Paul's* Church-yard. MDCCIV.

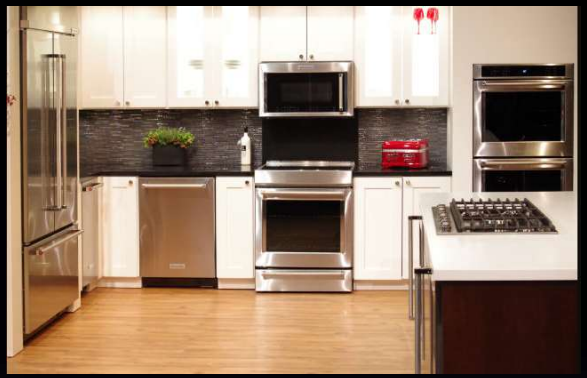
The first, 1704, edition of *Opticks: or, a treatise of the reflexions, refractions, inflexions and colours of light.*

History of the transistor – Wikipedia "After WWII, Shockley decided to attempt the building of a triode-like semiconductor device. He secured funding and lab space, and went to work on the problem with Bardeen and Brattain. John Bardeen eventually developed a new branch of quantum mechanics known as surface physics to account for the "odd" behavior they saw, and Bardeen and Walter Brattain eventually succeeded in building a working device."



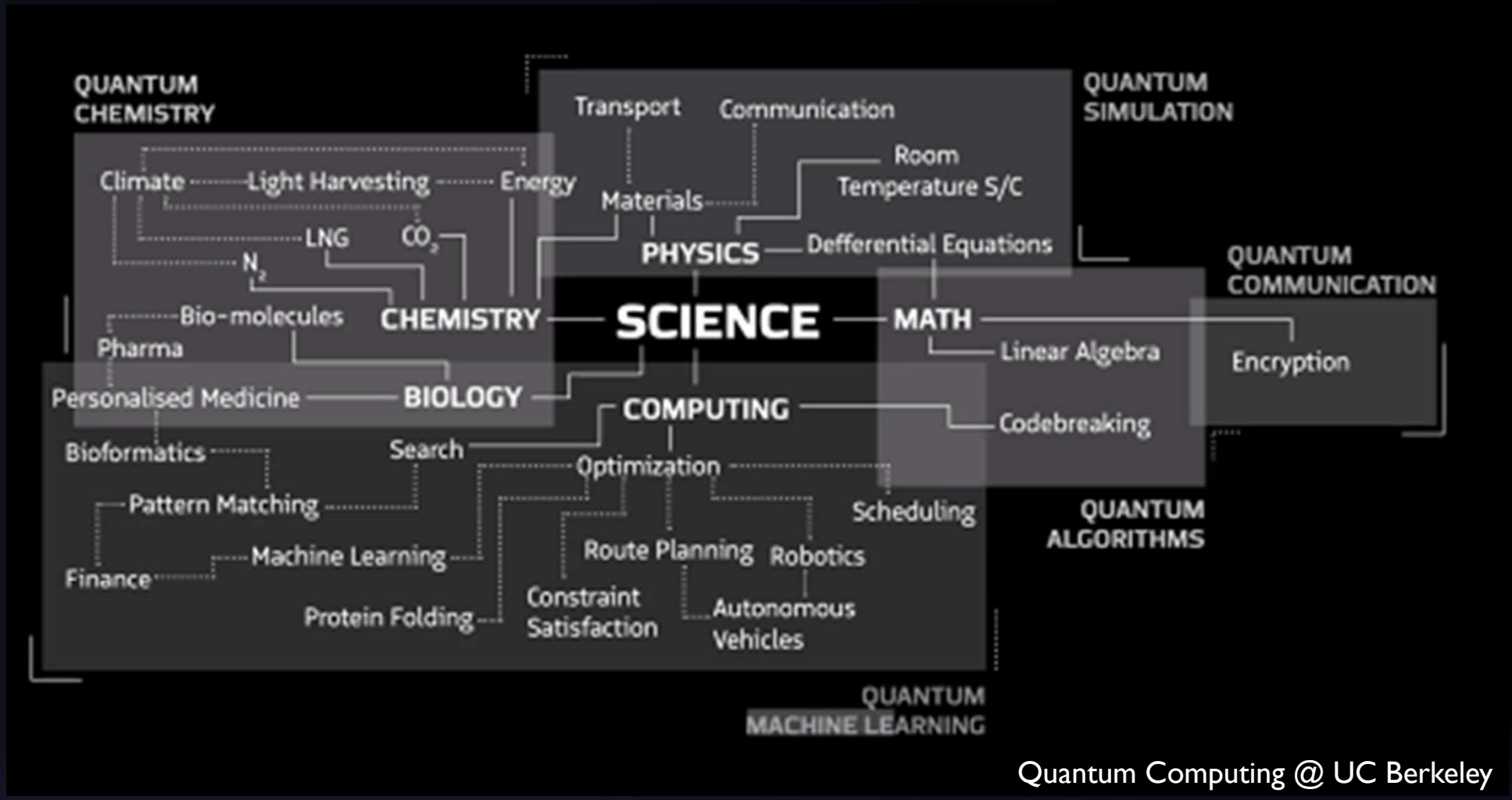






# Why should you care??

## Education and career opportunities.



An official website of the United States government Info

⟨quantum|gov⟩

ABOUT STRATEGY ACTION REPORTS NEWS NQCO Search...


Welcome to *quantum.gov*, the home of the National Quantum Initiative and ongoing activities to explore and promote Quantum Information Science. The National Quantum Initiative Act was signed into law on December 21, 2018. The purpose of

## RECENT REPORTS

- QIST Workforce Development National Strategic Plan, February 1, 2022
- Annual Report on the NQI Program Budget, December 6, 2021
- The Role of International Talent in Quantum Information Science, October 5, 2021

QED-C

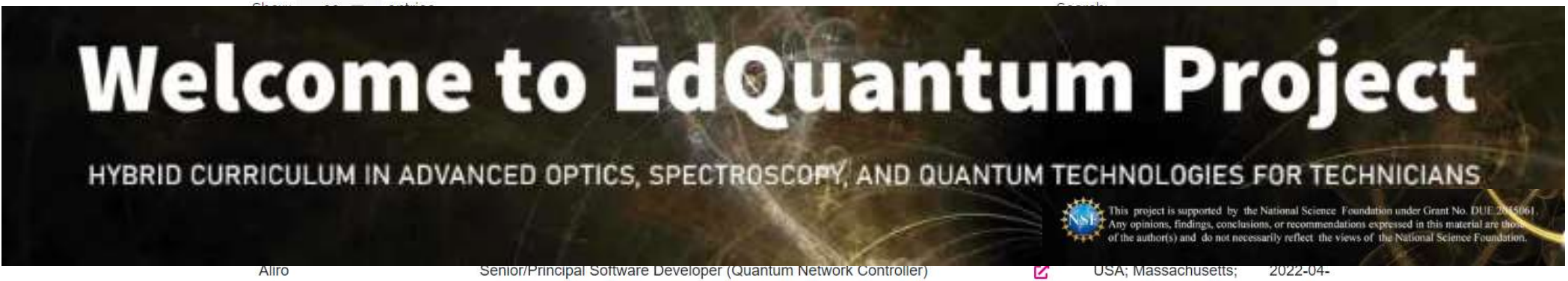
About | Membership | News & events | Blog | Contact us | Quantum jobs | Quantum Marketplace | For members

## Quantum jobs

Check out available listings of employment opportunities at QED-C members companies. Members include corporations, academic institutions, national laboratories and government agencies working in quantum.

*QED-C thanks Quantum Computing Report and Harrisburg University of Science and Technology for contributing to this list.*

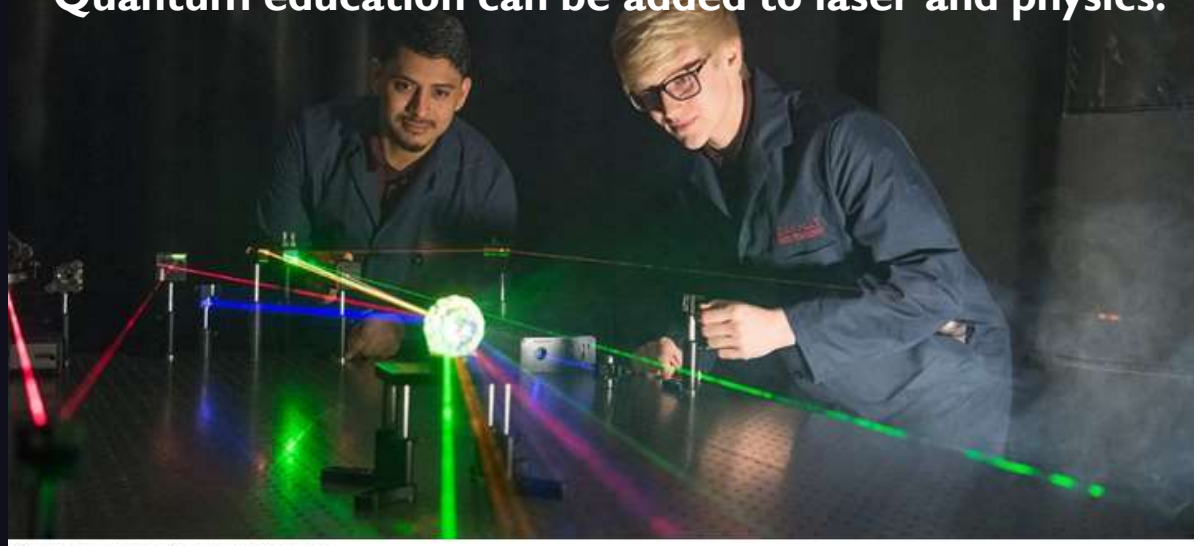
CORPORATE | ACADEMIC | GOV'T/NAT'L LABS/OTHER




| | | | | |
|---|---|---|---|---|
| Aliro | Senior/Principal Software Developer (Quantum Network Controller) | | USA; Massachusetts; Boston | 2022-04-16 |
| Aliro | Senior/Principal Software Developer (Quantum Network Protocols) | | USA; Massachusetts; Boston | 2022-04-16 |
| Amazon | 2022 Fall Applied Science Internship - Automated Reasoning, Computer Vision, | | Canada; Ontario; | 2022-05- |

Quantum Technician Skills and Competencies for the Emerging Quantum 2.0 Industry (SPIE Optical Engineering)
Authors: Mo Hasanovic, Chrys Panayiotou, Donn Silberman, Paul Stimers, and Celia Merzbacher
Available on-line Apr. 9, 2022 - Open Access at the link above. To be published in hardcopy form August 2022

**We are educating and training tomorrow's workforce now.**
**Quantum education can be added to laser and physics.**



*Credit: Indian Hills Community College*

Administration

BRIEFING ROOM

# FACT SHEET: President Biden Announces Two Presidential Directives Advancing Quantum Technologies

MAY 04, 2022 • STATEMENTS AND RELEASES



# QUANTUM INFORMATION SCIENCE AND TECHNOLOGY WORKFORCE DEVELOPMENT NATIONAL STRATEGIC PLAN

*A Report by the*
SUBCOMMITTEE ON QUANTUM INFORMATION SCIENCE

COMMITTEE ON SCIENCE

*of the*
NATIONAL SCIENCE & TECHNOLOGY COUNCIL

February 2022

## Who We Are

The National Q-12 Education Partnership includes tech companies, scientific professional societies, academics, and the NSF-funded Q2Work Program. Together, we aim to support and grow a quantum workforce that is diverse and equitable, such that the QIS innovators of tomorrow can make discoveries, invent new technologies and drive societal change. We want to increase opportunities, access, and quality of age-appropriate QIS educational experiences for students from all backgrounds.




Home | National Q-12 Education Partnership | UIUC (q12education.org)

PCC LASERTECH

**Are you seeking a career with cutting-edge technology that pays well? With the in-demand skills of laser technology, you can work in aerospace, medicine, robotics, manufacturing, entertainment, forensics, or defense!**

The Optics and Photonics College Network (OPCN) is Association of Postsecondary Photonics Technician Educators.

LASER-TEC NSF

A National Science Foundation Center

LASER-TEC – Center for Laser & Fiber Optics Education

44

Partner Colleges

# Pasadena City College

http://pasadena.edu/academics/degrees-and-certificates/certificates-of-achievement/laser-technology.php

NASA Jet Propulsion Laboratory
California Institute of Technology

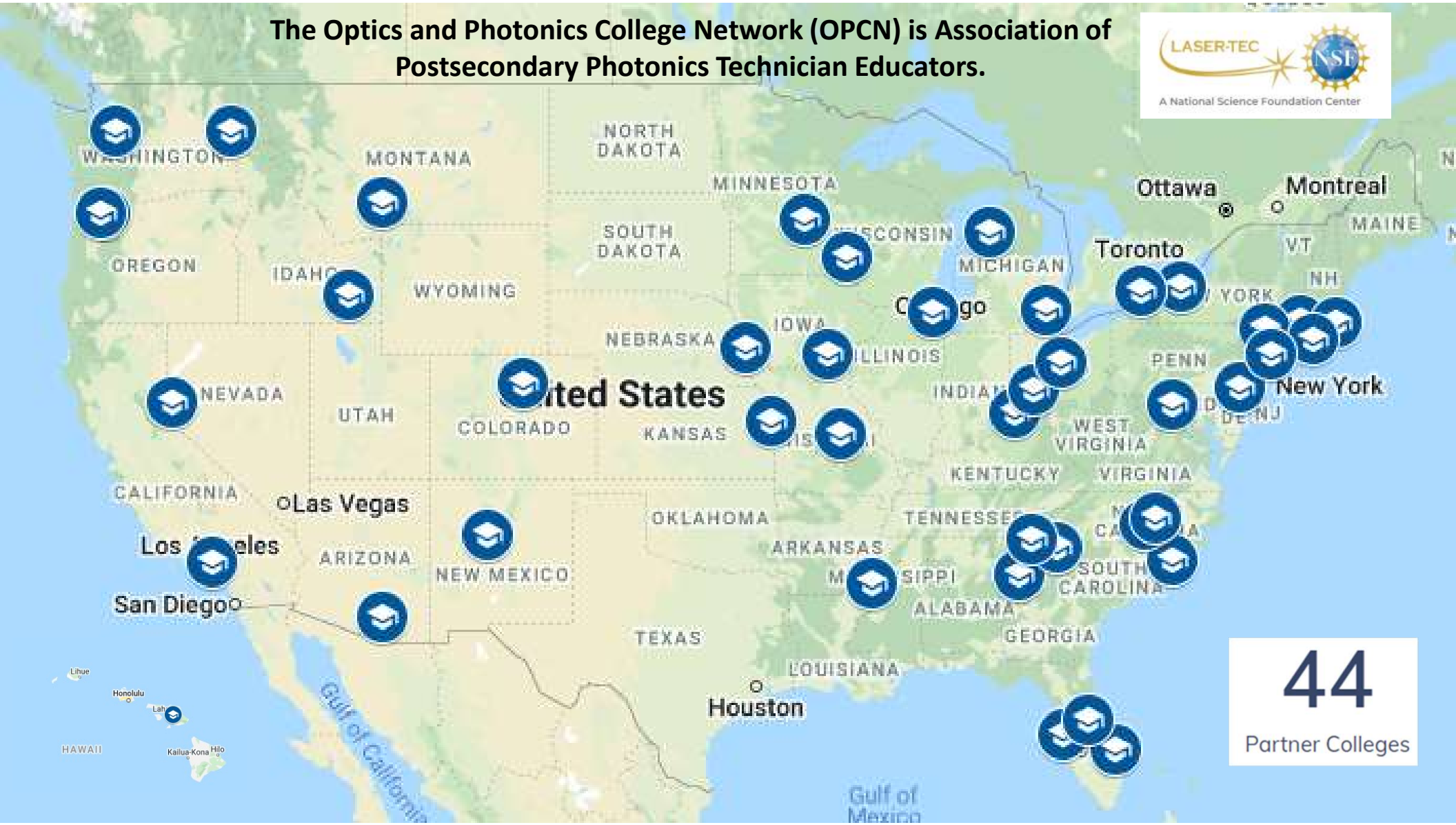
## Be Laser-Focused

LaserTech is the use of lasers, cameras, lenses, mirrors, sensors, displays, fiber optics, and other technical devices that interact with light.

- ✓ Earn skills to be immediately hired as a technician
- ✓ Be prepared for success in a university engineering program
- ✓ Advance your careeer by mastering more technically demanding skills

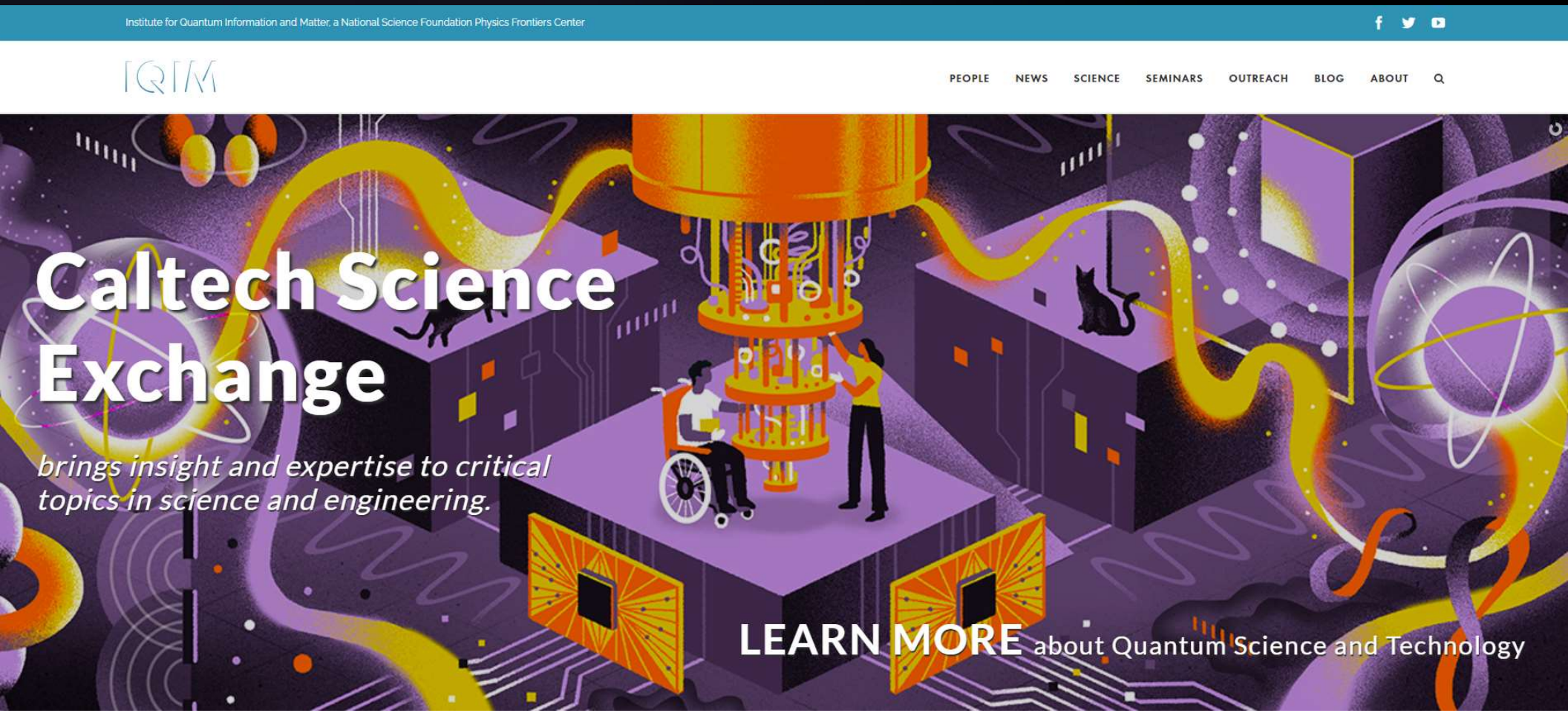
**naturalsciences@pasadena.edu**

**The Optics and Photonics College Network (OPCN) is Association of Postsecondary Photonics Technician Educators.**



**Institute for Quantum Information and Matter, a National Science Foundation Physics Frontiers Center**

**California Institute of Technology**



# Quantum Computers & Cybersecurity

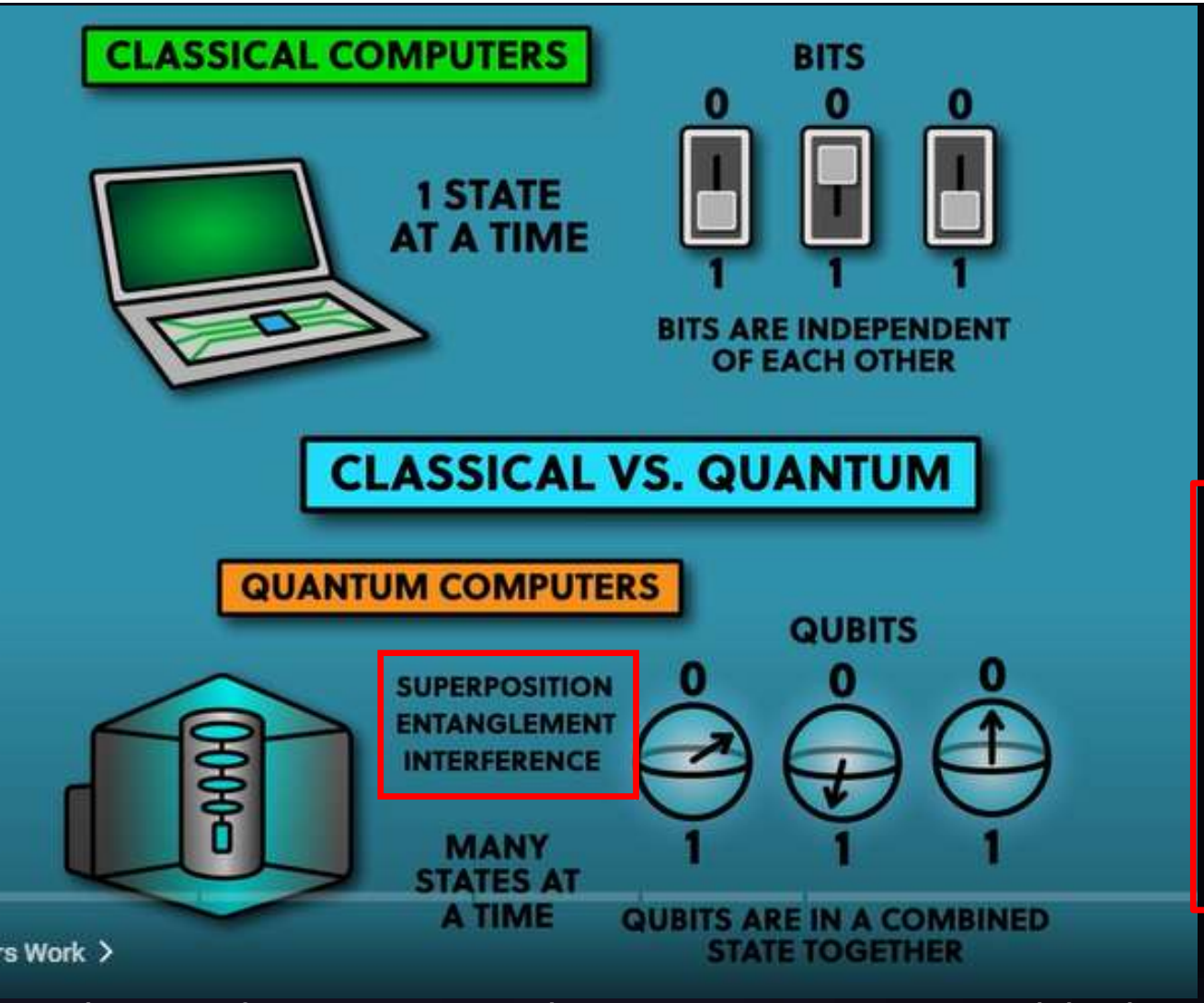
Including cryptocurrencies and blockchain technologies

## Risks & Opportunities

The global race to develop practical quantum computers that can 'hack' all current encryption technologies
Against the implementation of quantum resistant encryption technologies.

**Intellectual property (IP) -**

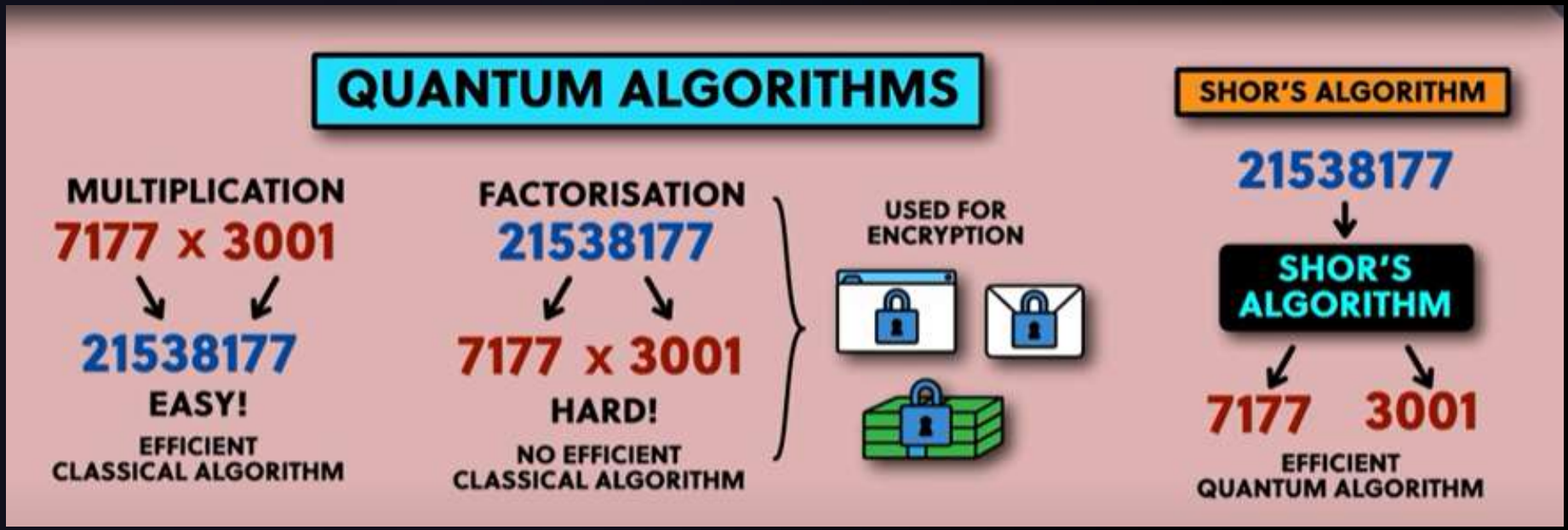
- **in the public domain via patents and published papers**
- **Trade Secrets – held 'close to the vest'**




The Map of Quantum Computing | Quantum Computers Explained
DoS - Domain of Science – YouTube

**Superposition**
**Entanglement**
**Interference**

**Einstein's**
**"Spooky Action at a Distance"**




**Classical Computing**

**Quantum Computing**

The Map of Quantum Computing | Quantum Computers Explained
DoS - Domain of Science – YouTube

Preventing “hack now, decrypt later” attacks with quantum safe VPNs (quantumtechcongress.com)

# Preventing “hack now, decrypt later” attacks with quantum safe VPNs


**04/11/2022**

Almost all the data we transmit today is protected by quantum-vulnerable algorithms, such as RSA. Attackers can record this encrypted data, knowing they can decrypt it in the future on a quantum computer.

This talk from September 2021, we discussed a case study in which we defend against this threat, using virtual private networks (VPNs) combined with quantum-safe algorithms and key generation methods with Nick Van Duyn, Senior Solutions Architect – Cybersecurity, Cambridge Quantum.

# Federal officials want State & Local Govt to Prepare Now for Post-Quantum Security

Quantum computing strong enough to break traditional encryption methods is looming on the horizon — and federal officials want state and local governments to start planning for that future now.

December 17, 2021 • Jule Pattison-Gordon

**https://www.govtech.com/computing/state-local-govt-can-prepare-now-for-post-quantum-security**

Article Landing Page | opticsage (donn601.wixsite.com)


**In response to the threat to RSA and ECC encryption algorithms imposed by Quantum Computers, the National Institute of Science and Technology (NIST) has been leading an effort to define replacement cryptographic algorithms**

The goal is to create standards for new asymmetric encryption algorithms capable of withstanding attacks from Quantum Computers.

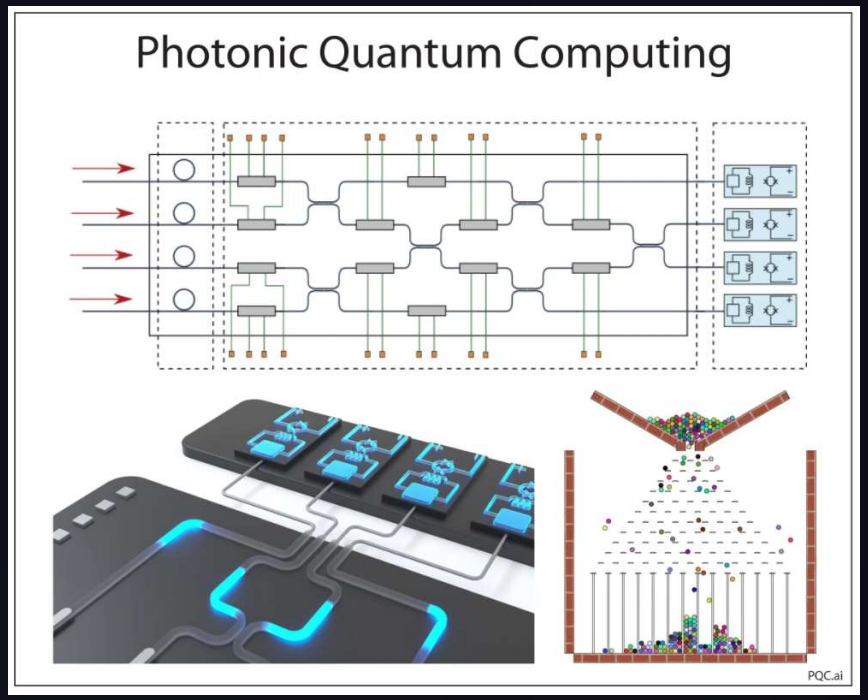
NIST started this process started in 2015 and has stated that fully published standards will be available in 2024.

[NIST Post Quantum Crypto timelines: avoiding the dangerous misconception - TechNative]

DECEMBER 20, 2021 *by* DAVID D. NOLTE

# Twenty Years at Light Speed: The Future of Photonic Quantum Computing

DECEMBER 20, 2021 *BY* DAVID D. NOLTE




Twenty Years at Light Speed: The Future of Photonic Quantum Computing | Galileo Unbound (galileo-unbound.blog)

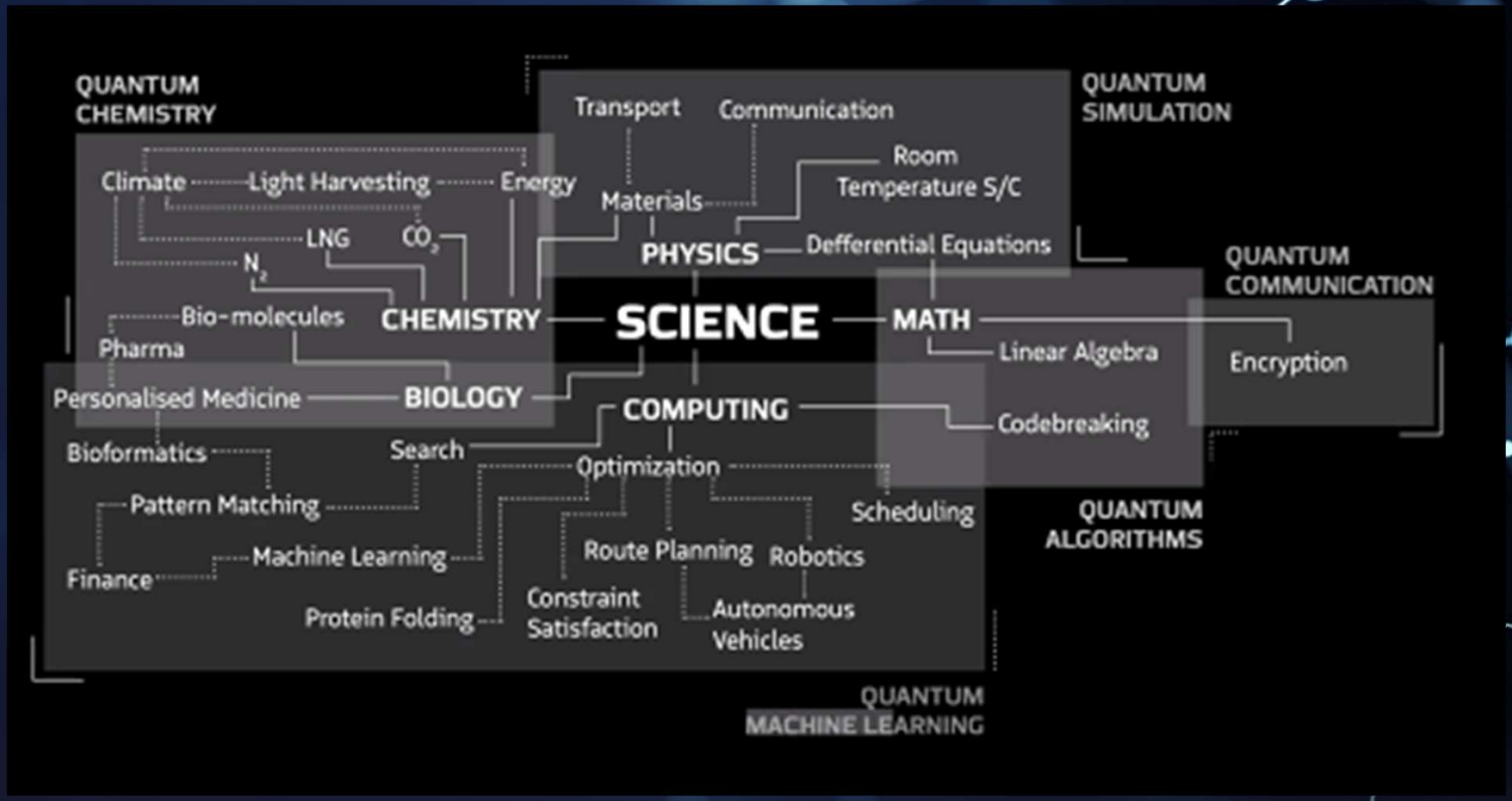
## The Quantum Era Emerges - How PI Fast Automated Alignment Enables Practical Manufacturing

PI (Physik Instrumente) L.P.


Silicon photonics wafer testers require much higher precision and alignment algorithm complexity compared to classical semiconductor wafer probers. The image shows PI's double sided alignment system for fast NxM alignment of SiP devices Cascade Microtech's CM300xi photonics-enabled wafer probe station. (Image: Cascade Microtech, a FormFactor company)

Quantum Technology, Alignment & Nanopositioning | PI (pi-usa.us)

# Many More Quantum Applications



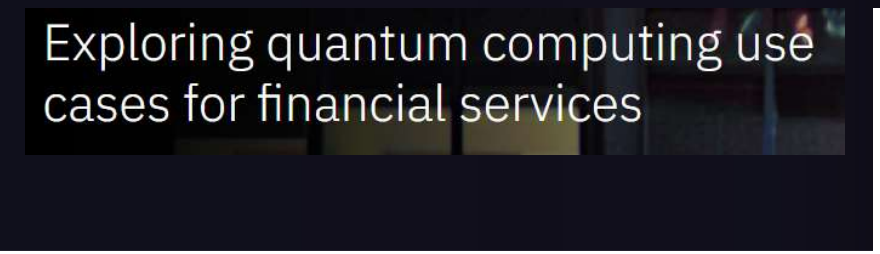
## Quantum Computing Applications

1. Quantum computing use cases for financial services | IBM
2. The Future of Quantum Drug Discovery - Cambridge Quantum
3. Quantum computer models a chemical reaction (scitation.org)
4. Quantum Computing: Accelerating the Digitization of Chemistry • EFMaterials Blog
5. Quantum Computing in Oil and Gas | Accenture
6. Inside Google's Quantum Computing Data Center
7. Quantum ML - Quantum: Machine Learning & Analytics
8. Exploring quantum computing use cases for manufacturing | IBM
9. University of Arizona Awarded $26M to Architect the Quantum Internet

*High School Quantum | opticsage (donn601.wixsite.com)*

1. Better Batteries
2. Cleaner Fertilization
3. Traffic Optimization
4. Weather Forecasting and Climate Change
5. Improving Solar Panels
6. Quantum Systems Simulations
7. Quantum Sensors
8. The Quantum Internet

# IBM Quantum solutions




## Benefits of the Quantum Era

Quantum computing's business value for financial services institutions result from four main scenarios:

— Enhancing investment gains

— Reducing capital requirements

— Opening new investment opportunities

— Improving the identification and management of risk and compliance

# IBM Quantum solutions

## Exploring quantum computing use cases for financial services


## Benefits of the Quantum Era

Quantum computing's business value for financial services institutions result from four main scenarios:

— Enhancing investment gains

— Reducing capital requirements

— Opening new investment opportunities

— Improving the identification and management of risk and compliance

# Quantum Computing: Accelerating the Digitization of Chemistry

August 25, 2020 | In Solution | By Ryan Esner

– Companies creating semiconductors, magnets, and superconductors will now be able to more precisely predict and optimize the structure of their solid-state materials.

– Tech companies creating OLED displays will now move away from endless trial-and-error methods to achieve desired brightness and hue of colors: thanks to simulation techniques, materials are simulated accurately before the first stage of production even begins.

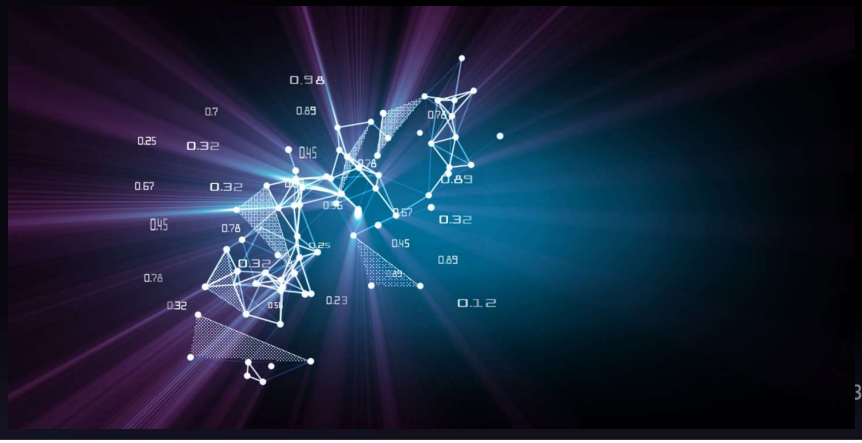
– Catalyst design will be made more accurate, reducing research costs and, more importantly, making catalyzed processes less energy intensive. In other words, catalysis will advance exponentially.

– Drug discovery depends heavily on biochemical interactions; by optimizing the simulation process of pharmaceuticals and helping labs accelerate the research process, better drugs will be synthesized in less time.

– The in-depth study of molecular structure allowed by quantum computers will enable researchers to take the investigation of proteins and biomaterials to the next level and will allow for the creation of next-generation optical materials.

## Quantum chemistry – the last frontier of materials science

Quantum Computing: Accelerating the Digitization of Chemistry • EFMaterials Blog



Accenture Energy

# Finding the holy grail with quantum computing in oil and gas

JULY 18, 2018

**Ely Colón**

**SENIOR PRINCIPAL – SUPPLY CHAIN AND OPERATIONS, DATA SCIENCE**

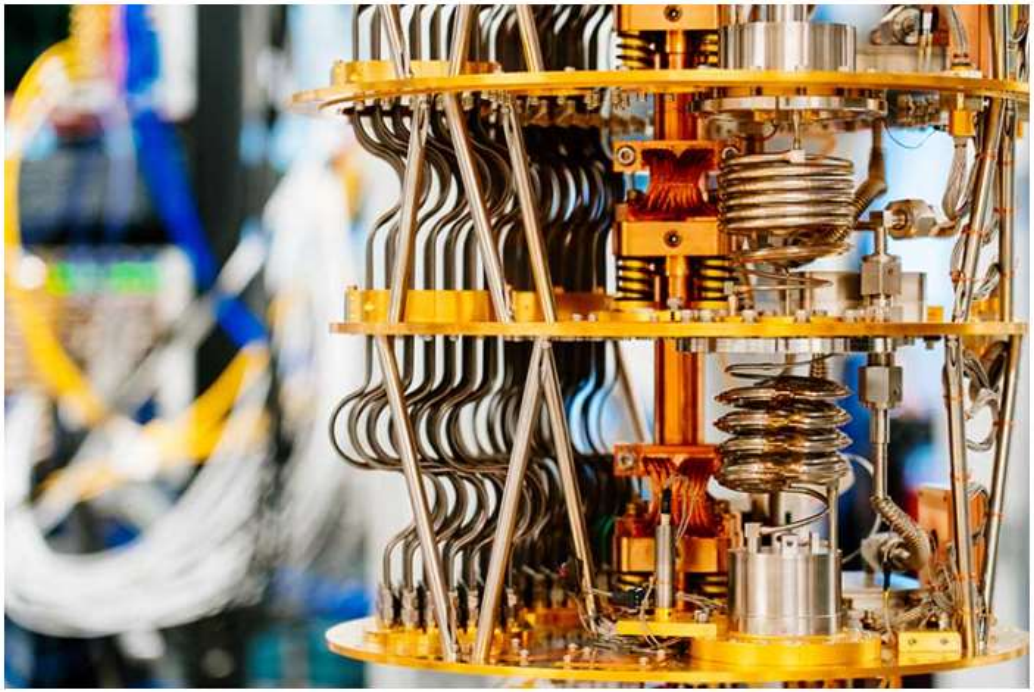
Ely is an executive focused on Integrated Planning and Fulfilment Analytics.

Six key questions can guide you to apply quantum computing strategically to enable the holy grail for oil and gas organizations—the driverless supply chain:

1. What **processes** (such as extraction or transportation) should be optimized from reservoir-to-end-customer?
2. What are the current **optimization limits** for each supply chain silo'ed process?
3. What is the likely **untapped value** for each separate, locally optimized process?
4. What **enterprise objectives** are you trying to achieve? (identify best and worst case scenarios to align with corporate strategy).
5. What would your ideal **end-to-end supply chain** system look like, including enterprise constraints and decision variables?
6. What should your **roadmap** look like and where should you start to experiment?

# Inside Google's Quantum Computing Data Center

BY RICH MILLER - NOVEMBER 22, 2021 — LEAVE A COMMENT



One of the cryostats at the Google Quantum AI Lab in Santa Barbara, Calif. (Image: Google)

Source: Interior of one of Google's Data Center, www.google.com/about/datacenters/

## The Quantum Consortium QED·C

Quantum Technician Skills and Competencies for the Emerging Quantum 2.0 Industry (SPIE Optical Engineering)
Authors: Mo Hasanovic, Chrys Panayiotou, Donn Silberman, Paul Stimers, and Celia Merzbacher
Available on-line Apr. 9, 2022 - Open Access at the link above. To be published in hardcopy form August 2022

Inside Google's Quantum Computing Data Center (datacenterfrontier.com)

## Welcome to EdQuantum Project

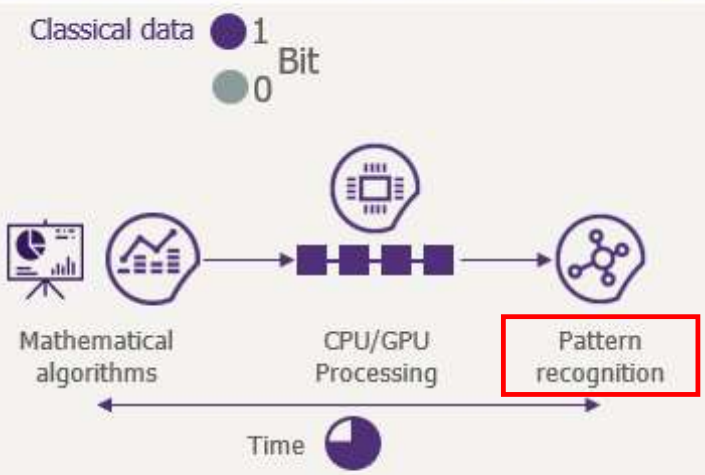
HYBRID CURRICULUM IN ADVANCED OPTICS, SPECTROSCOPY, AND QUANTUM TECHNOLOGIES FOR TECHNICIANS

This project is supported by the National Science Foundation under Grant No. DUE-2055961. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

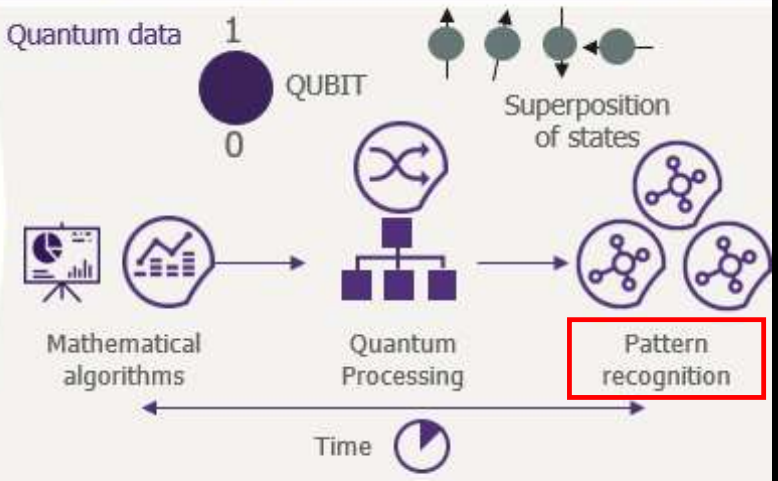
# Machine Learning

Quantum ML - Quantum: Machine Learning & Analytics (ml2quantum.com)

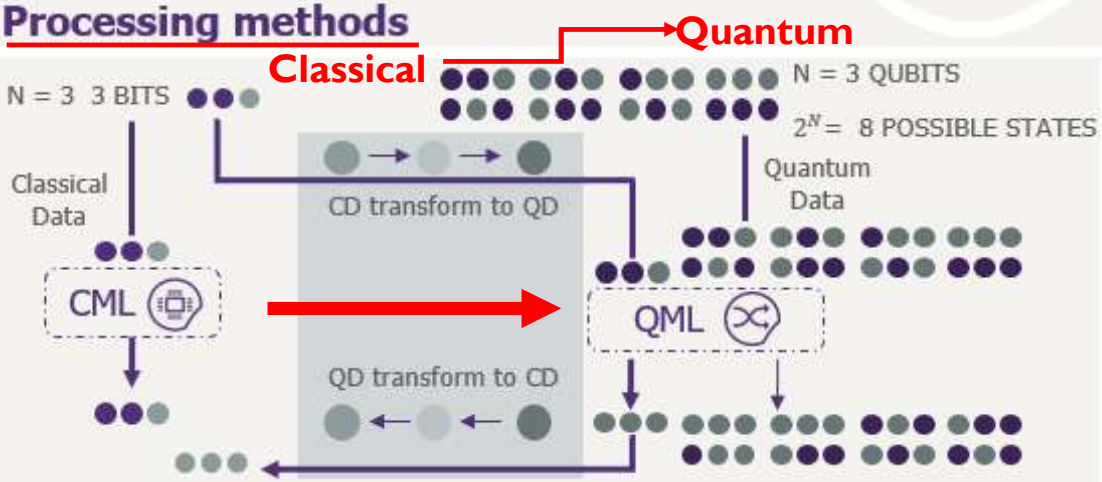
## Classical Machine Learning - CML



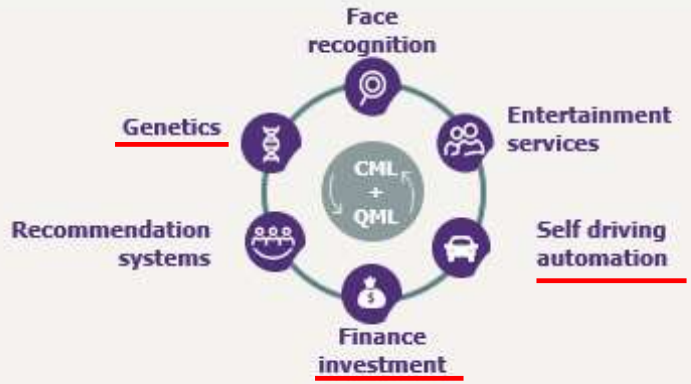

## Quantum Machine Learning - QML



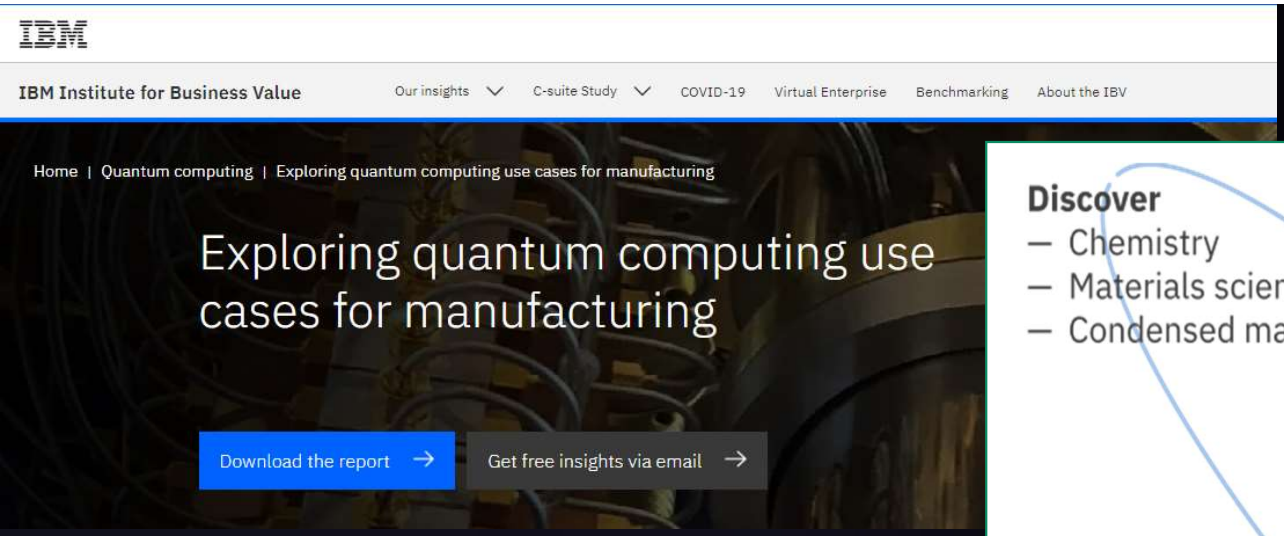

## Processing methods

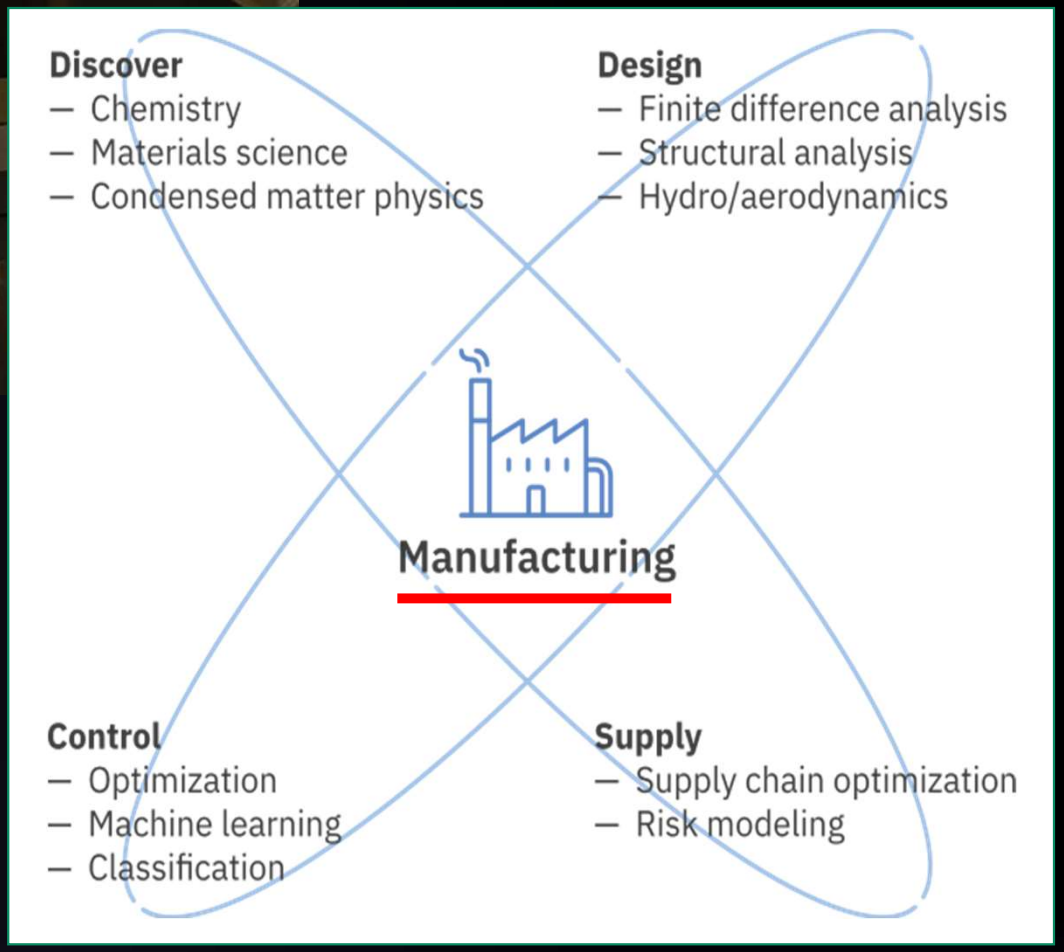



## Applications




Microsoft, Google, Honeywell, and Amazon




**Exploring quantum computing use cases for manufacturing | IBM**

# Telecommunications

Quantum computing is just one of the many functions towards the development of a quantum network that will deliver the quantum Internet

# The Quantum Internet

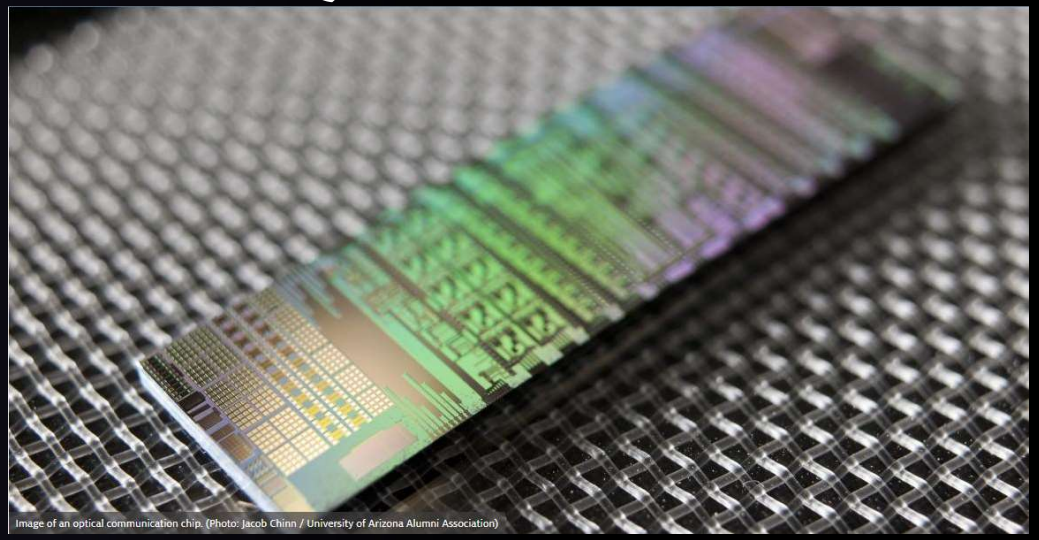



Image of an optical communication chip. (Photo: Jacob Chinn / University of Arizona Alumni Association)

**University of Arizona Awarded $26M to Architect the Quantum Internet | News | College of Engineering | The University of Arizona**

# Pathways for High School & College Students

What can you do to get involved with the Quantum World?

1. Be interested
2. Find a Mentor
3. Take Action

# Get involved with the Quantum World.

1. **Find good mentors**
    1. Start with your Physics Teacher
2. **Take Action:**
    1. Go to my website, click on links and read articles
    2. Watch YouTube videos on Quantum
    3. Find hands-on workshops close to home
    4. Take on-line courses
    5. Got to a college that offers quantum courses
    6. Take an internship that works in the field
    7. Join a club or start one your self


This is my business card – you can have one - FREE

# On-line and In-Person Resources

# Quantum for Students

This web page is a resource for students who may have seen my presentation.

Click here to download a pdf version of the slides. If you would like to give a version of this presentation, contact Donn directly.

## Quantum Educational Resources

Available Courses | qBraid

DoS - Domain of Science - YouTube

Map of Quantum Computing Poster – DFTBA

Qiskit - IBM's Open Source Quantum Computing Resource

Quantumapalooza 2020 Harrisburg University

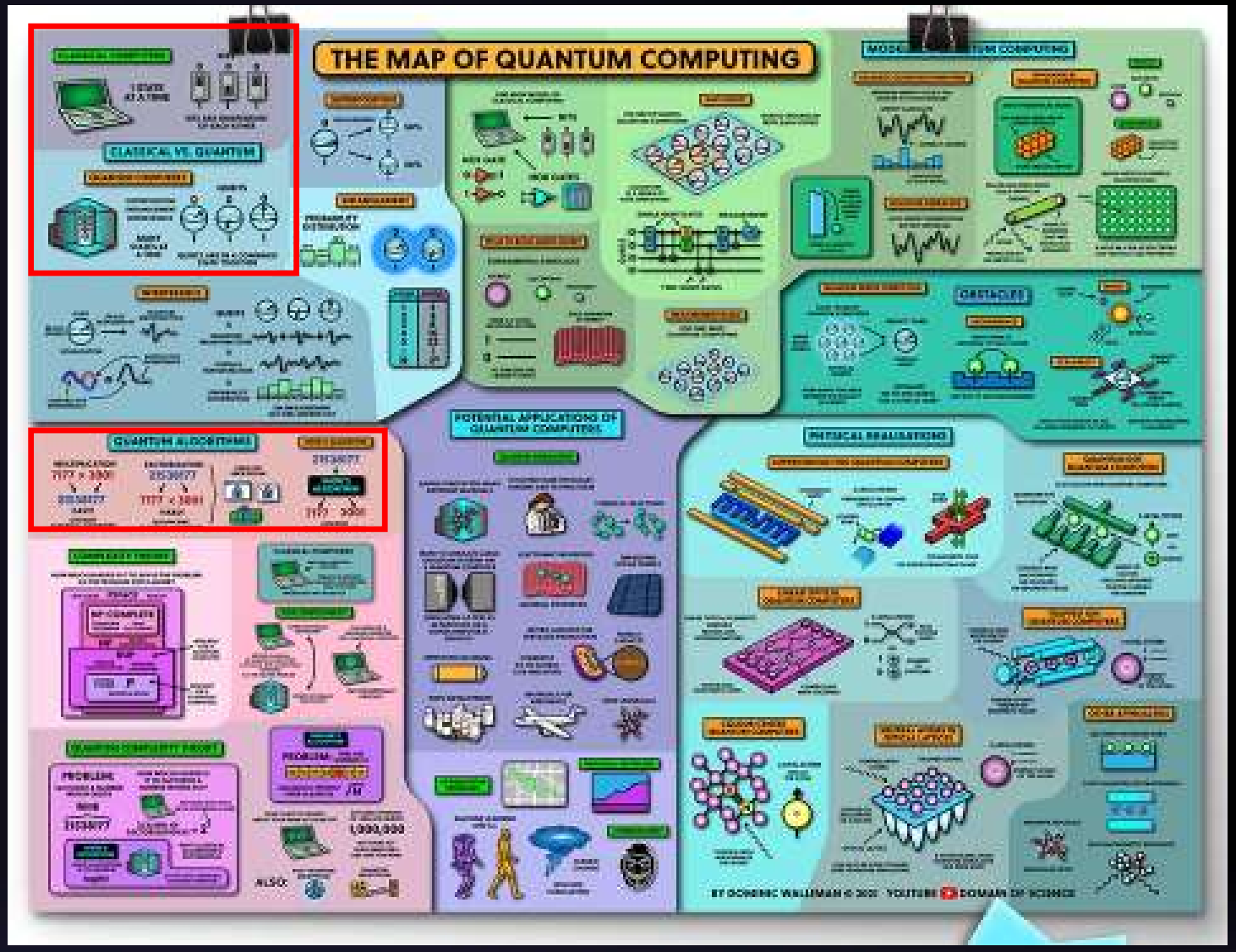
QuVis (st-andrews.ac.uk)

Key Concepts for Future QIS Learners (illinois.edu)

Schrödinger's Class | Institute for Quantum Computing | University of Waterloo (uwaterloo.ca)

(for the Schrödinger's Class materials, contact Donn directly)

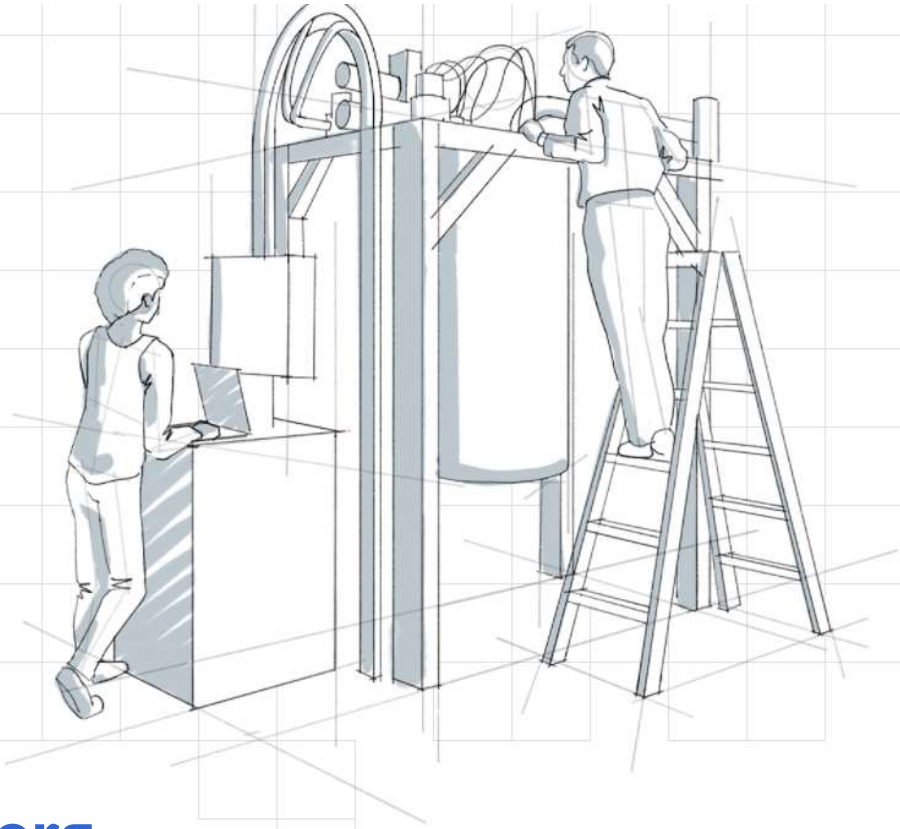
Quantum for Students | opticsage (donn601.wixsite.com)


THE MAP OF QUANTUM COMPUTING
CLASSICAL VS. QUANTUM
QUANTUM ALGORITHMS
POTENTIAL APPLICATIONS OF QUANTUM COMPUTING
PHYSICAL REALISATIONS
OBSTACLES

# Open-Source Quantum Development

Qiskit [quiss-kit] is an open-source SDK for working with quantum computers at the level of pulses, circuits, and application modules.

Get started



**Qiskit.org**

## Quick Start

When you are looking to start Qiskit, you have two options. You can start Qiskit locally, which is much more secure and private, or you get started with Jupyter Notebooks hosted in IBM Quantum Lab.

**IBM's Education System – it's FREE**

### Start locally

To install Qiskit locally, you will need Python 3.6+. Although it is not required, we recommend using a virtual environment with Anaconda.

### Start Online

Get started in the cloud wi

HARRISBURG UNIVERSITY OF SCIENCE AND TECHNOLOGY

# Quantumapalooza*

* *Definition*: Suffix. apalooza. Forms the name of a promotional event such as a presentation. Emphasizes or exaggerates the element of a situation.

[Data powered by Harrisburg Quantum™, Contact: quantum@HarrisburgU.edu ]
Display time zone: US/Eastern Show Past Events

## Endless list of FREE online learning opportunities for the Quantum Computing community!
## (10 upcoming events listed below.)

**Workforce Skills-Readiness Classifications (Quantum Computing):**
(This is a work-in-progress, draft; comments welcome!)

| Level | Name | Type of question(s) an individual is presently asking |
|---|---|---|
| 000 | Quantum Curious | What is Quantum Computing? |
| 100 | Quantum Explorer | What is a Ket? |
| 200 | Quantum Climber | How to do a Controlled-Z 90-degree Rotation? |
| 300 | Quantum Enabled | Why does Shor's Algorithm utilize Modular Arithmetic? |
| 400 | Quantum Ready | How to make my Algorithm Robust to all that Error? |
| 500 | Quantum Professional | How can I Monetize my Skills? |

This table is a WIP, send your improvement ideas to quantum@HarrisburgU.edu

(note: The past 0 events (since May 18, 2020) are placed at the far bottom of this page)

## Wed, May 04

### Quantum Computing and Machine Learning

**Wed., May. 04, 2022, 8:00am-9:00am (EDT/GMT-0400)** [Start time local timezone converter]

selfURL Content Level: 300 (For Quantum Enabled)

NOTE: THIS IS AN EARLY TIME SLOT SESSION - repeated on Thu May 5 at 3:30-4:30 pm ET. Quantum computing is poised to potentially have an impact on machine learning methods. In this seminar, we will cover the current state and future prospects of machine learning with quantum computers. This includes algorithms and models such as quantum kernel estimation, variational quantum classifiers, quantum neural networks, and quantum generative-adversarial networks (QGANs). We will also demonstrate the capabilities of the Qiskit Machine Learning open source software project. Note that this is part 3 of a 6-session series on Quantum Computing on Apr 13/14, Apr 20/21, May 4/5, May 18/19, Jun 1/2, and Jun 15/16. The sessions are not prerequisites for each other, and are not recorded. We will provide reference links and do quick recaps of previous content as required, so if you miss an earlier session, you can still get value from subsequent sessions. Presenter: Sean Wagner Sean is a Research Scientist and a Quantum Technical Ambassador at IBM. When he's not programming and experimenting with Qiskit, Sean spends his time working with researchers at academic institutions and industry partners in Canada on projects involving high-performance computing, hardware acceleration, quantum computing, and data science and AI. Dr. Wagner holds a B.A.Sc. degree in Computer Engineering from the University of Waterloo, and M.A.Sc. and Ph.D. degrees in Electrical and Computer Engineering from the University of Toronto. It is recommended that you register at this Webex link ahead of time to receive a calendar invite and reminder. https://ibm.webex.com/ibm/j.php?RGID=r6f8ab05838f0851bbfe4b46f282f84d4

http://2020.quantumapalooza.com/

https://www.st-andrews.ac.uk/physics/quvis/

# QuVis The Quantum Mechanics Visualisation Project

University of St Andrews

Search for simulations | About | For Instructors | Research | Donate | News

**HTML5 Simulations**
Suitable for Tablet and PC

**Flash Simulations**
Suitable for PC

**Donate**
Support QuVis

## SORT

Newest | Alphabetical

## TOPIC

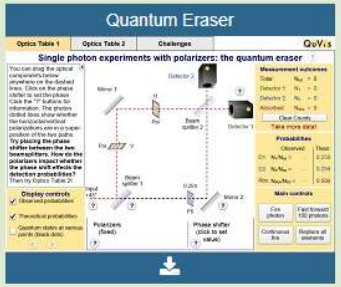
- [x] All Topics
- [ ] Classical systems
- [ ] Single photon experiments
- [ ] Linear algebra
- [ ] One dimensional potentials
- [ ] Two dimensional potentials
- [ ] Multiple particles
- [ ] Spin angular momentum
- [ ] Entanglement
- [ ] Fundamental concepts
- [ ] Quantum information

## LEVEL

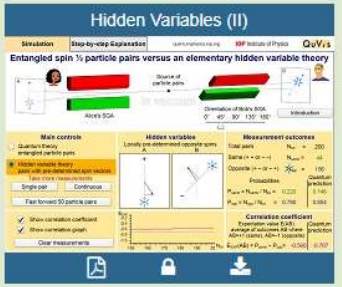
- [x] All Levels
- [ ] Introductory
- [ ] Advanced

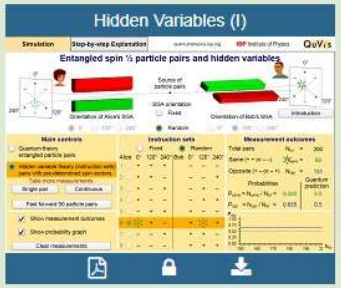
## LANGUAGE

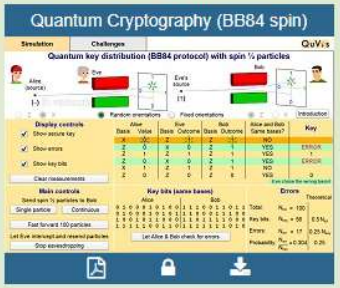
- [ ] All languages
- [x] English

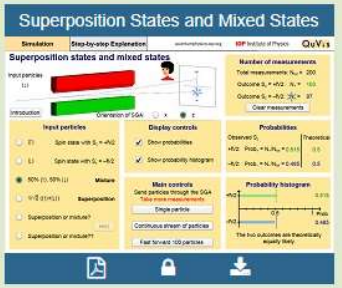


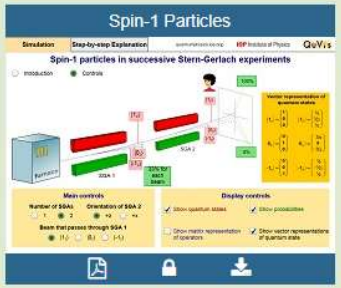


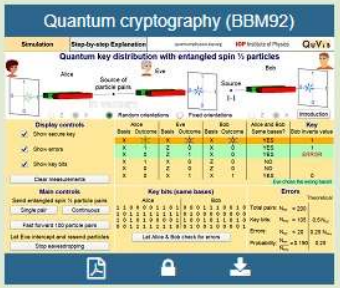


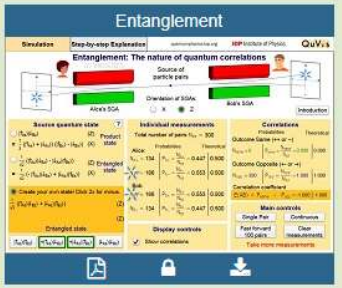



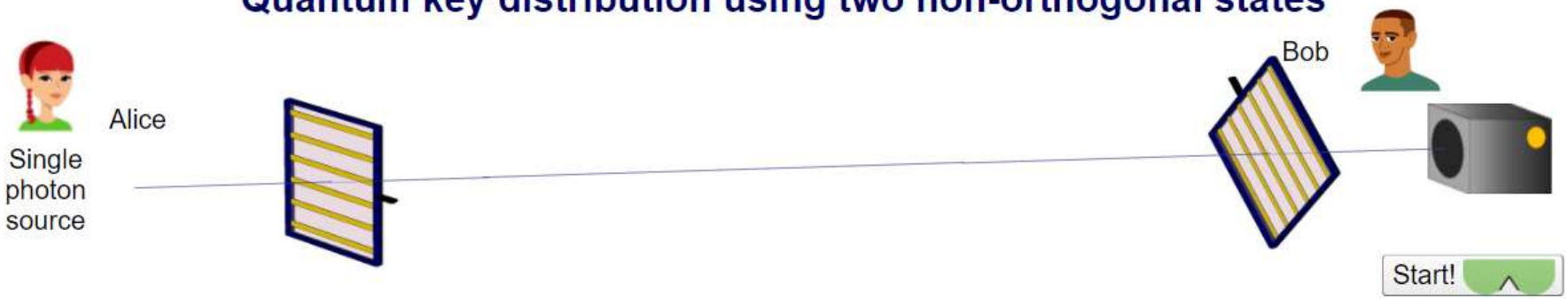



https://www.st-andrews.ac.uk/physics/quvis/

Simulation | Challenges

QuVis

# Quantum key distribution using two non-orthogonal states




Alice and Bob need to share a secret perfectly random sequence of zeros and ones (a so-called secure key), but cannot meet in person. Classically this is impossible, as they can never be certain that the key was not intercepted during transmission. Quantum mechanics makes secure key generation possible!

In this simulation, you can help Alice and Bob generate a secure key with polarized photons using the so-called B92 protocol. Alice randomly prepares each photon with either 0° (horizontal) or +45° polarization. The horizontal polarization is assigned a bit value of 0, the +45° polarization a bit value of 1.

Alice sends the polarized photon to Bob, who is equipped with a polarization analyzer and a single photon detector. For each measurement Bob randomly sets his analyzer to one of two directions orthogonal to Alice's directions, so either 90° or -45°. Alice informs Bob whenever she sends a photon. If Bob detects the photon, he knows with certainty the polarization and hence the bit value (0 or 1) sent by Alice. For example, if Bob detects a photon when measuring along 90°, he knows that Alice sent a photon with +45° polarization (it cannot have been the 0° polarization) and thus with bit value 1. Bob can therefore assign detections with 90° a bit value of 1, and detections with -45° a bit value of 0.

If Bob does not detect the photon, he cannot be certain which state Alice sent. Thus, Alice and Bob keep only those measurements where Bob detected a photon – this sequence of 0 and 1 bit values forms the key. Alice and Bob publicly communicate to determine which photons were detected. They then exchange a small number of their bit values (which they then discard as they are not anymore secure) to check for errors.

**Your goal is to help Alice and Bob decide whether or not they have generated a secure key. How can they tell that an eavesdropper Eve has infiltrated their experiment? Click on the virtual reality goggles that allow you to "see" the photons to start sending photons from Alice to Bob and to eavesdrop by intercepting and resending photons.**

https://www.st-andrews.ac.uk/physics/quvis/

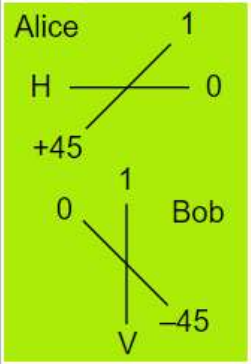
Simulation | Challenges

QuVis

# Quantum key distribution using two non-orthogonal states


H(0°) +45° Random polarizations Fixed polarizations V(90°) –45°

Introduction




## Display controls

- ☑ Show key generation
- ☑ Show key bits
- ☑ Show total errors

Clear measurements

| Alice Polarization | Alice Bit | Eve Polarization | Eve Detected? | Eve Sent | Bob Polarization | Bob Detected? | Key |
|---|---|---|---|---|---|---|---|
| 0° | 0 | | | | –45° | YES (0) | 0 |
| 0° | 0 | | | | 90° | no | |
| 0° | 0 | | | | 90° | no | |
| 0° | 0 | | | | –45° | YES (0) | 0 |
| 0° | 0 | | | | 90° | no | |

## Main controls

Send polarized photons to Bob

Single photon | Stop

Fast forward 100 photons

Let Eve intercept and resend photons

Eavesdrop!

## Most recent key bits (detected by Bob)

| Alice | Bob |
|---|---|
| 0 0 | 0 0 |

Let Alice & Bob compare 20 bits for errors

More measurements needed for error checking

## Errors (all measurements)

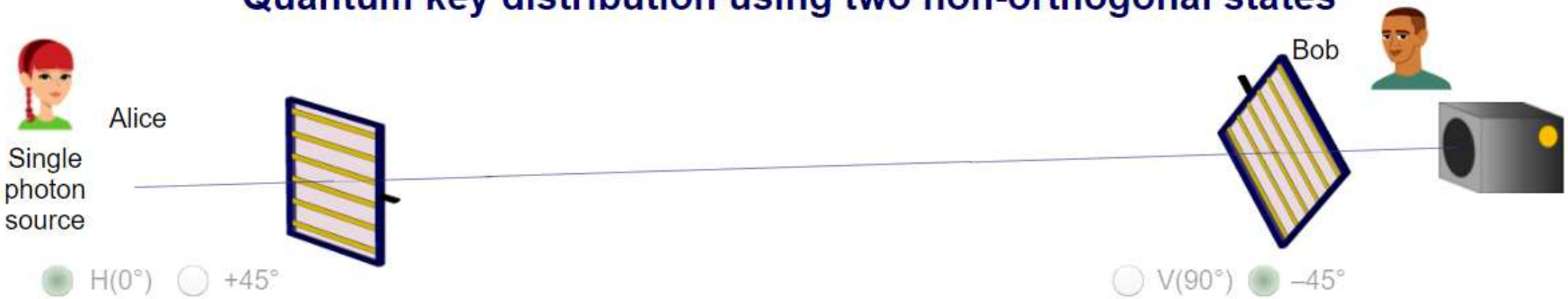
| | | Theoretical |
|---|---|---|
| Total: | $N_{tot} = 8$ | |
| Key bits: | $N_{key} = 2$ | $0.25\ N_{tot}$ |
| Errors: | $N_{err} = 0$ | 0 |
| Probability: | $\frac{N_{err}}{N_{key}} = 0.000$ | 0 |

https://www.st-andrews.ac.uk/physics/quvis/

Simulation | Challenges

QuVis

# Quantum key distribution using two non-orthogonal states




**Your score:** 15/100

Assuming no eavesdropper has intervened, what sequence of detections and non-detections could Bob have measured? Choose one or more.

- ☐ no , YES, YES, YES, no , YES
- ☑ YES, no , no , no , YES, no
- ☐ YES, YES, YES, no , YES, no
- ☑ no , no , no , YES, no , YES

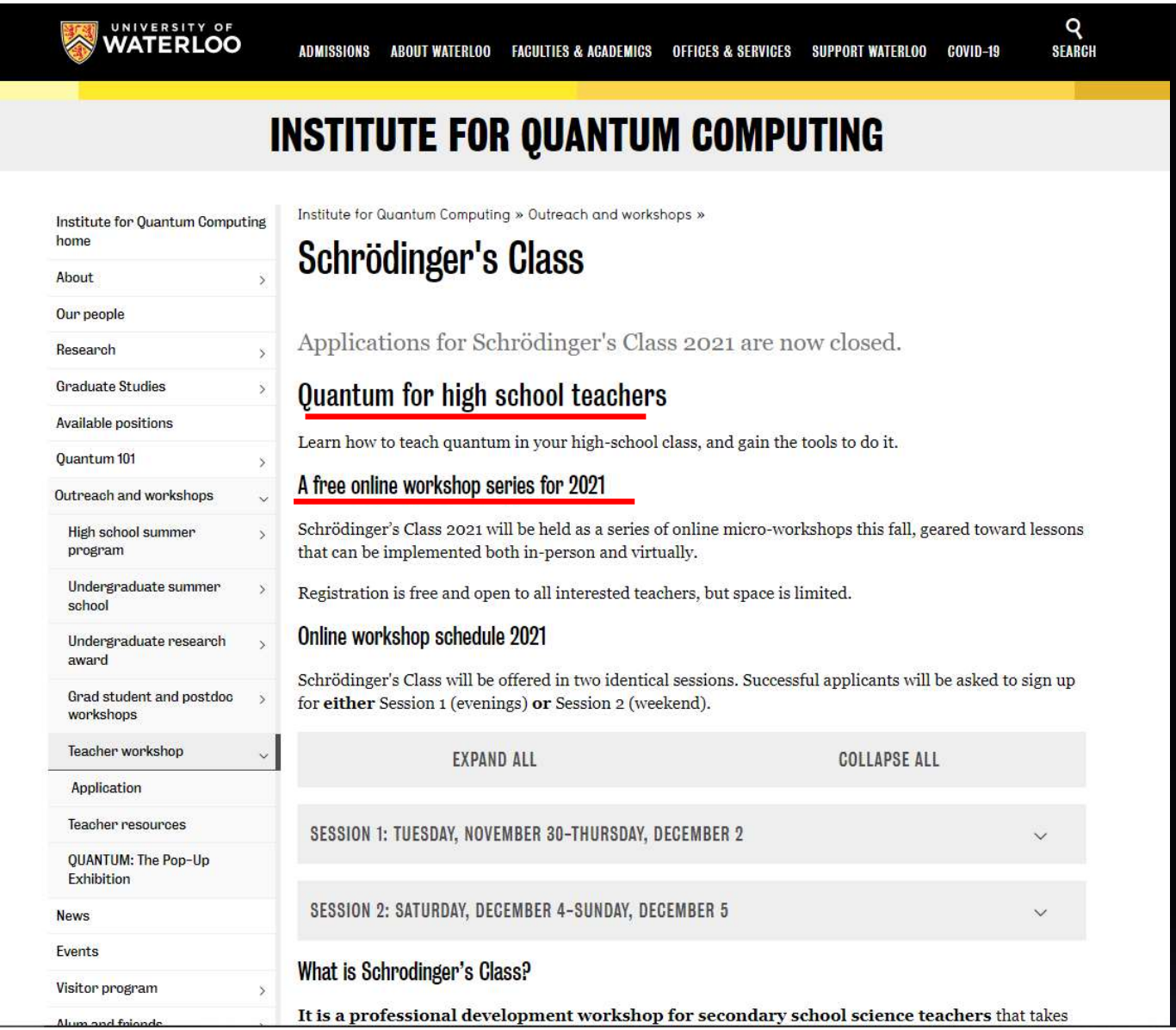
Submit

| Alice Polarization | Bit | Eve Polarization | Detected? | Sent | Bob Polarization | Detected? | Key |
|---|---|---|---|---|---|---|---|
| 0° | 0 | | | | –45° | ? | ? |
| 0° | 0 | | | | 90° | ? | ? |
| 0° | 0 | | | | 90° | ? | ? |
| 0° | 0 | | | | –45° | ? | ? |
| 0° | 0 | | | | –45° | ? | ? |
| +45° | 1 | | | | 90° | ? | ? |

Correct, congratulations! Bob does not detect the photon if his polarizer is orthogonal to Alice's polarizer. If Bob chooses a polarization 45° from Alice's polarization, 50% of the times he detects the photon.

1 ✓ — 2 — 3

4 — 5 — 6




Interested in attending a local Quantum Education Workshop ??


Follow the White rabbit
To learn more about:
Superposition
Entanglement
Interference
Einstein's
"Spooky Action at a Distance"

# Experience Life in the QuantumOptics Age

OpticsAge is a focal point for Donn Silberman's past Optics Education Adventures
Donn has retired from most of his educational outreach activities and his fulltime job at Starrett.
This website will be periodically maintained as an educational resource.

Donn is now focused on his Quantum Explorations and is consulting on EdQuantum.

## Contact Us

First Name

Last Name

Email *

Write a message

Submit

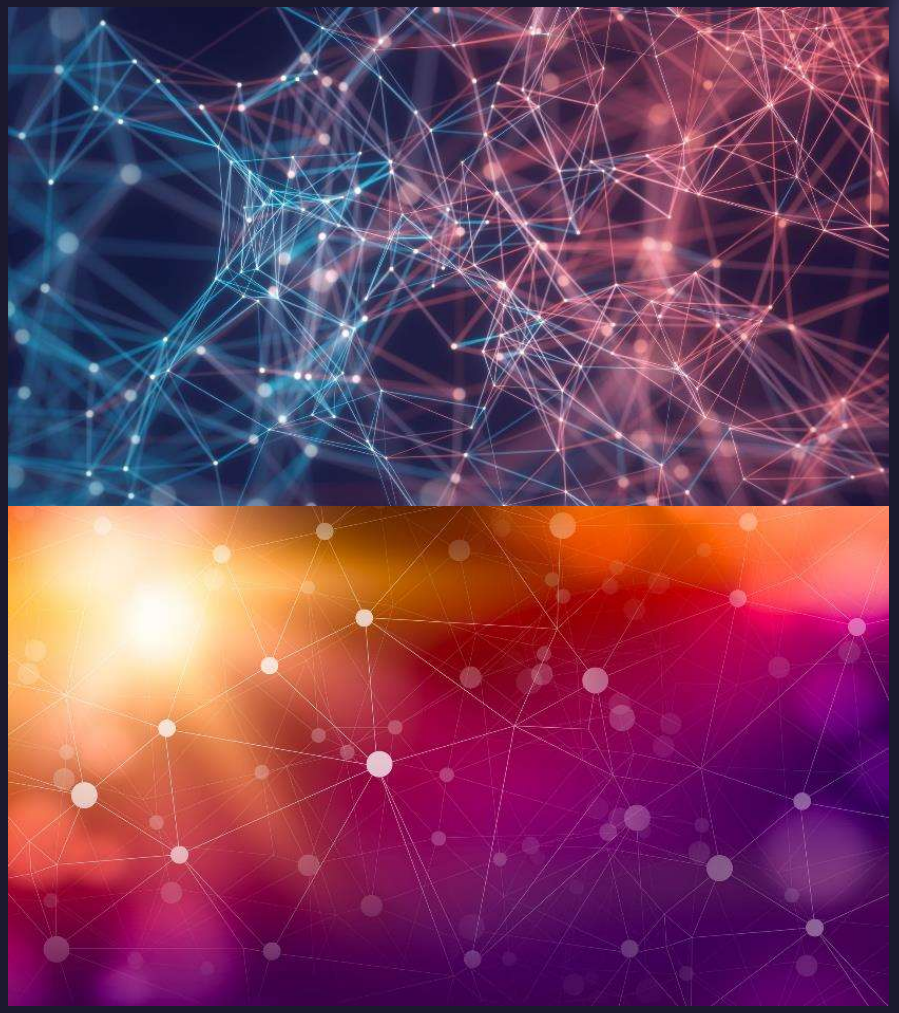
# Summary

- The Quantum World underlies our modern civilization.
- And Quantum is about take humanity to the next level.
- You can help make it happen.

# Thank You


## Donn Silberman

- Optics Institute of Southern California
- **http://oisc.net**

# Questions & Answers