Quantum computers: What are they for and how to make them

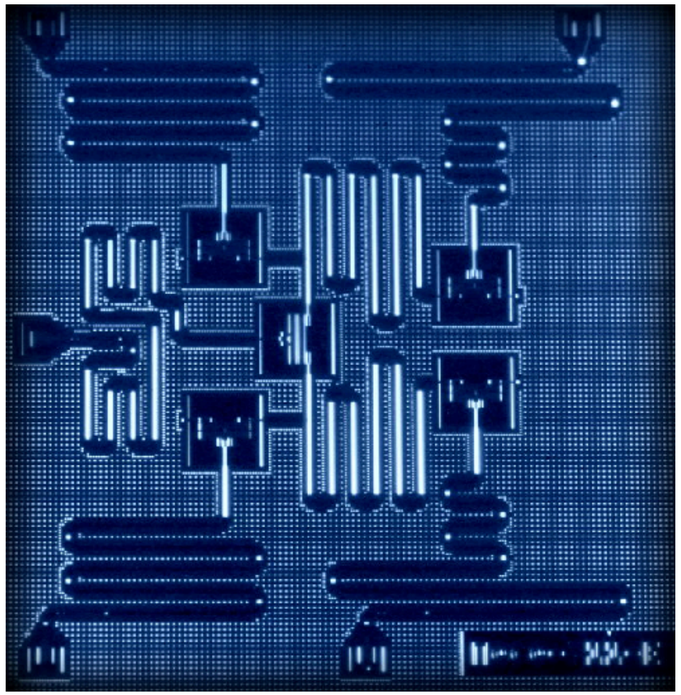
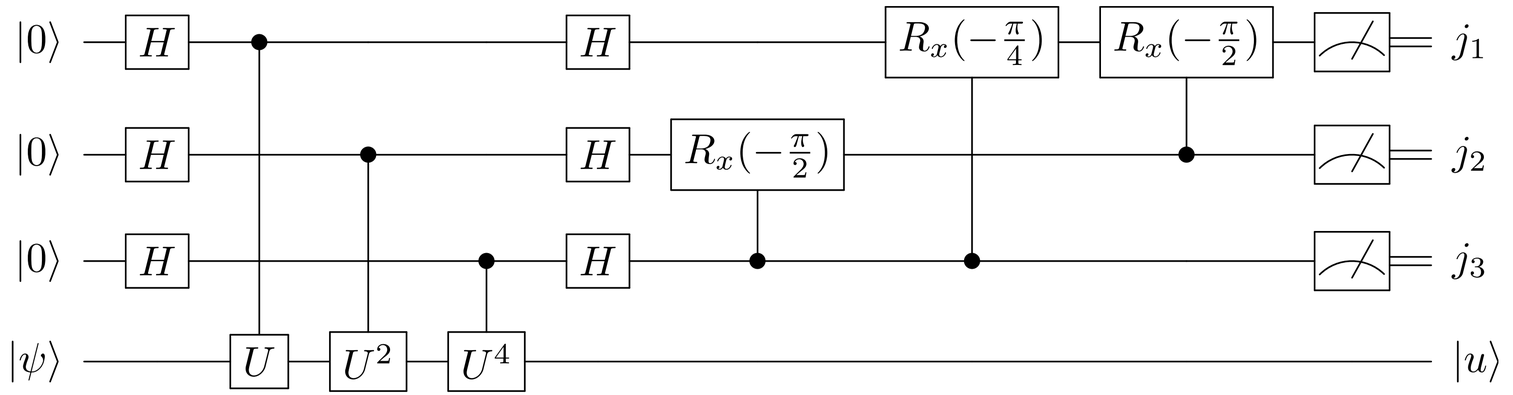


Image credit: IBM



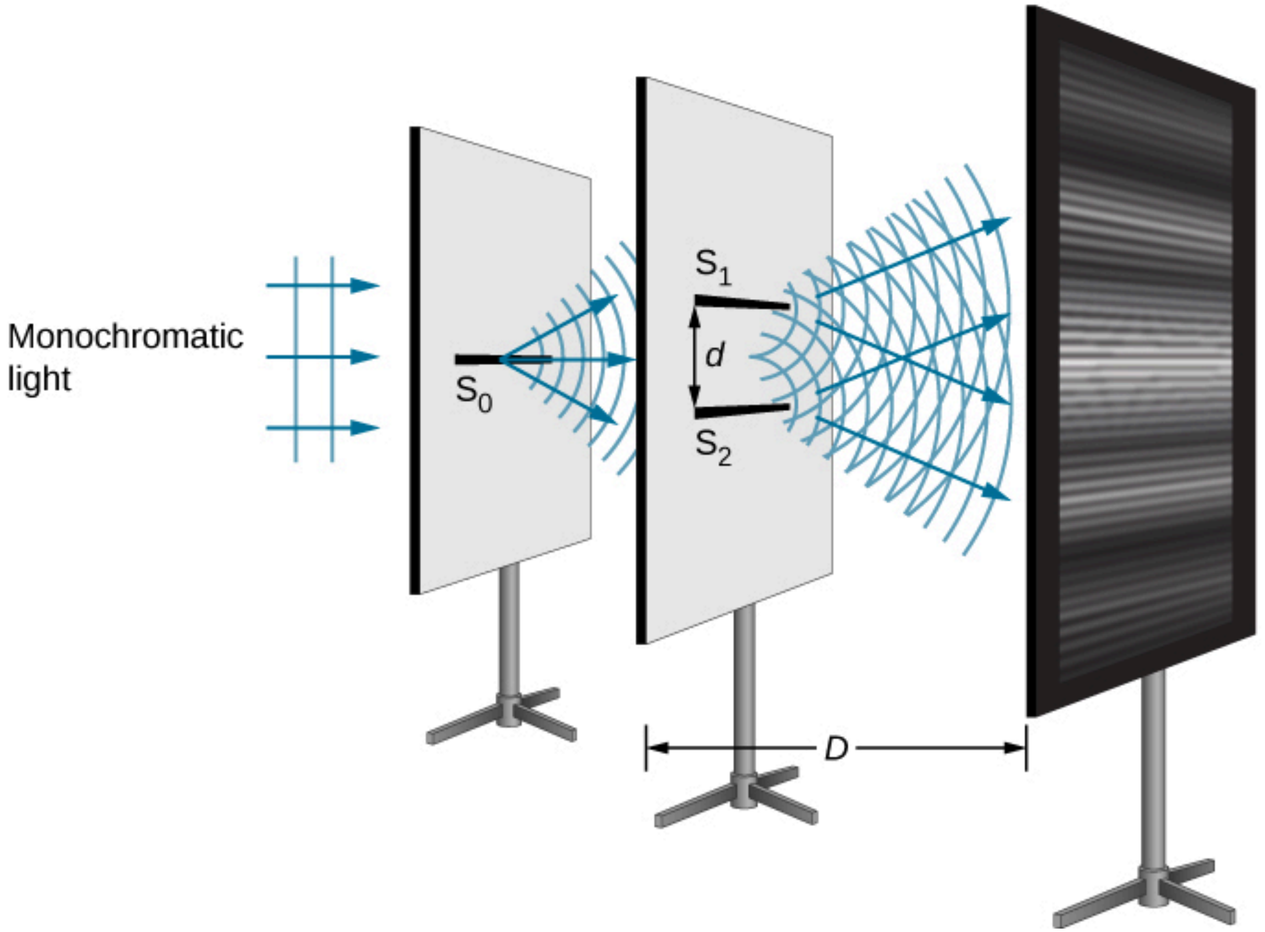
Rogério de Sousa (UVic) - Science Alive STEM speaker series, June 18, 2022

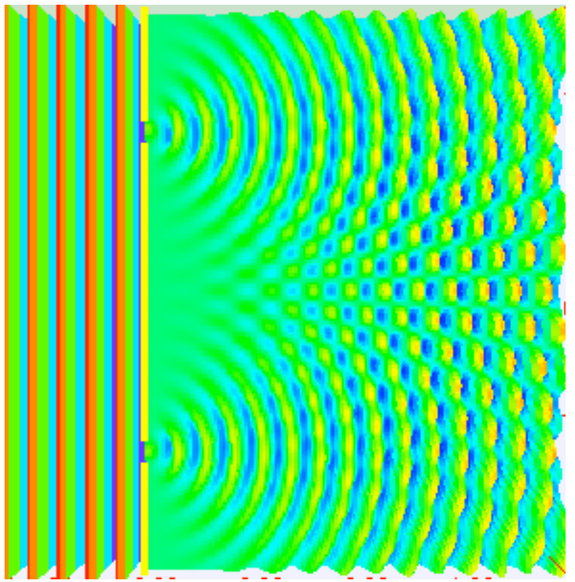
Territorial acknowledgement

“We acknowledge and respect the lək̓ʷəŋən peoples on whose traditional territory the university stands and the Songhees, Esquimalt and W̱SÁNEĆ peoples whose historical relationships with the land continue to this day”

Outreach for indigenous youth and K-12: http://quantum-bc.ca/learn/diversifying-talent-in-quantum-computing/

Two-slit experiment with light



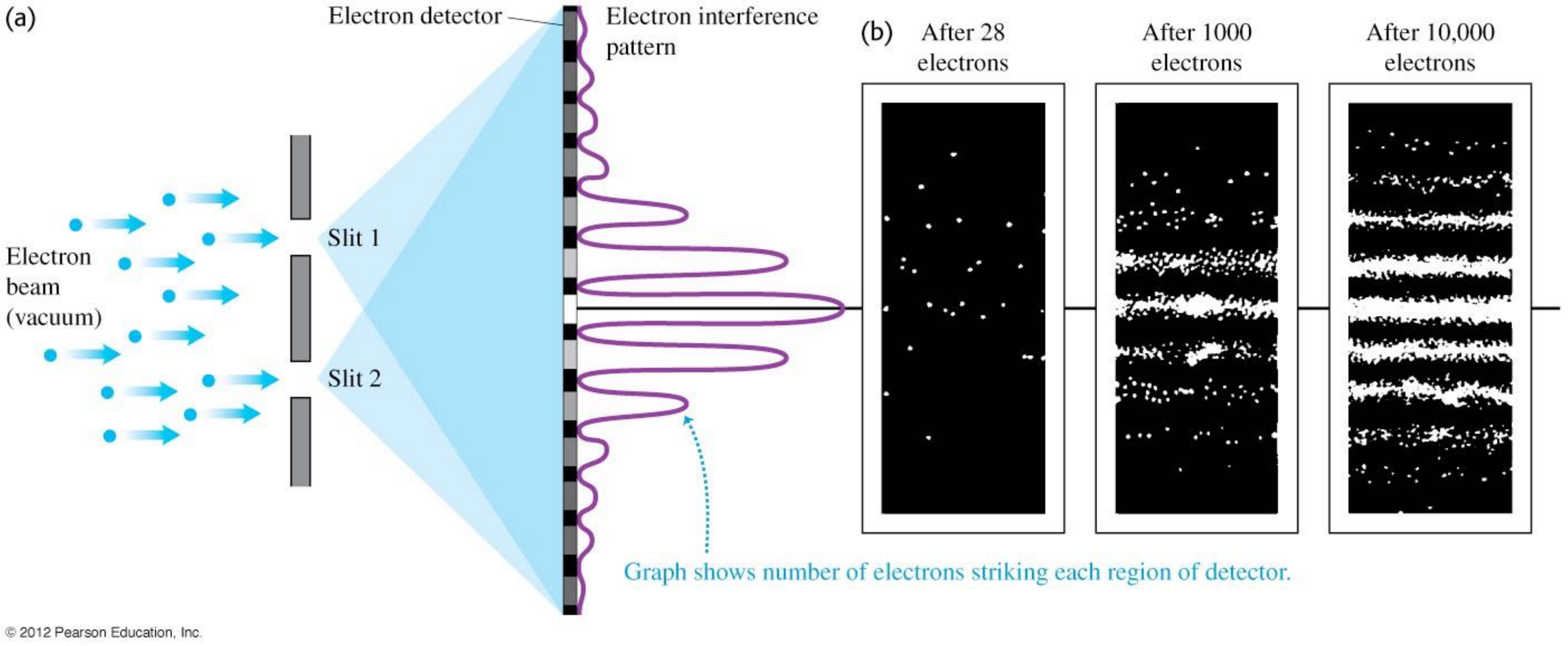


Evidence that light is a wave

Many thanks to Michel Lefebvre for suggesting this way of introducing quantum mechanics!

University Physics Volume 3 by OpenStax is licensed under Creative Commons Attribution License v4.0

Two-slit experiment with electrons

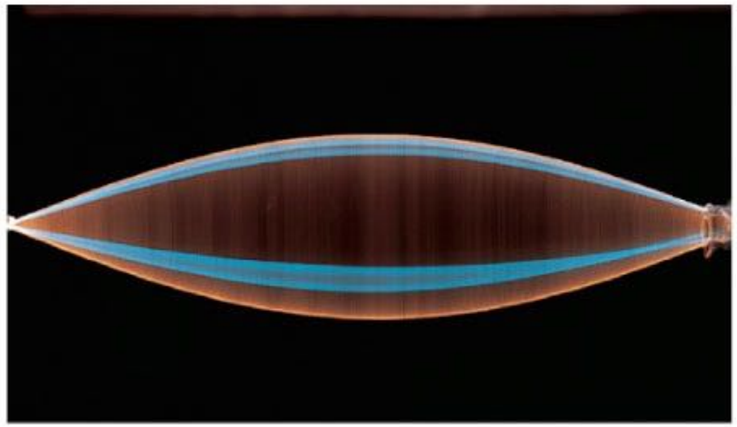


© 2012 Pearson Education, Inc.

Particles arrive one a time!!!
Probability given by the matter wave

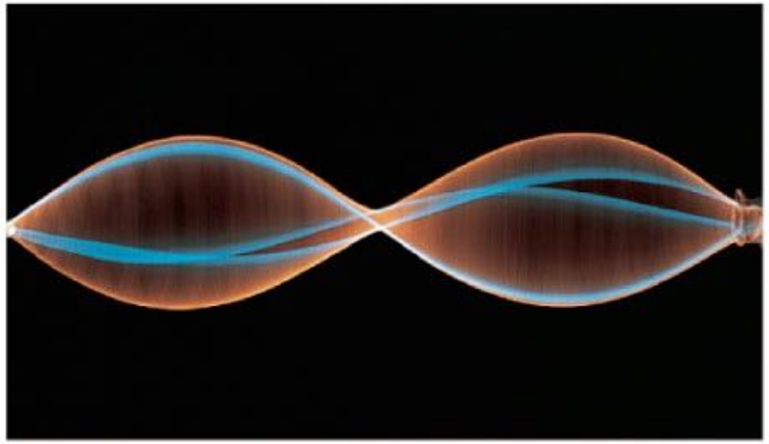
Standing waves

(a) String is one-half wavelength long.



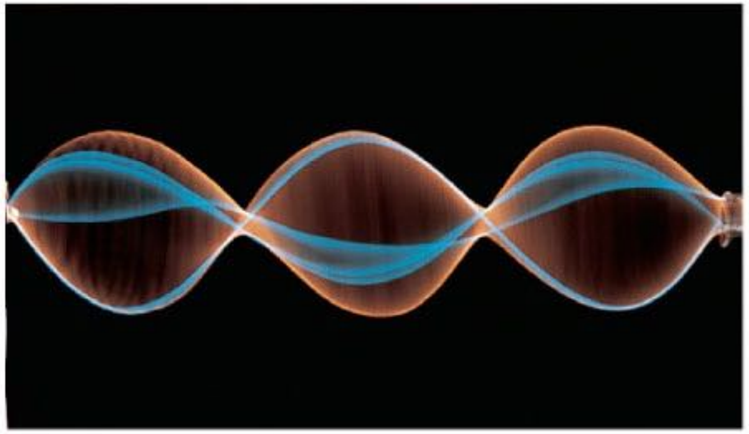
© 2012 Pearson Education, Inc.

(b) String is one wavelength long.



© 2012 Pearson Education, Inc.

(c) String is one and a half wavelengths long.

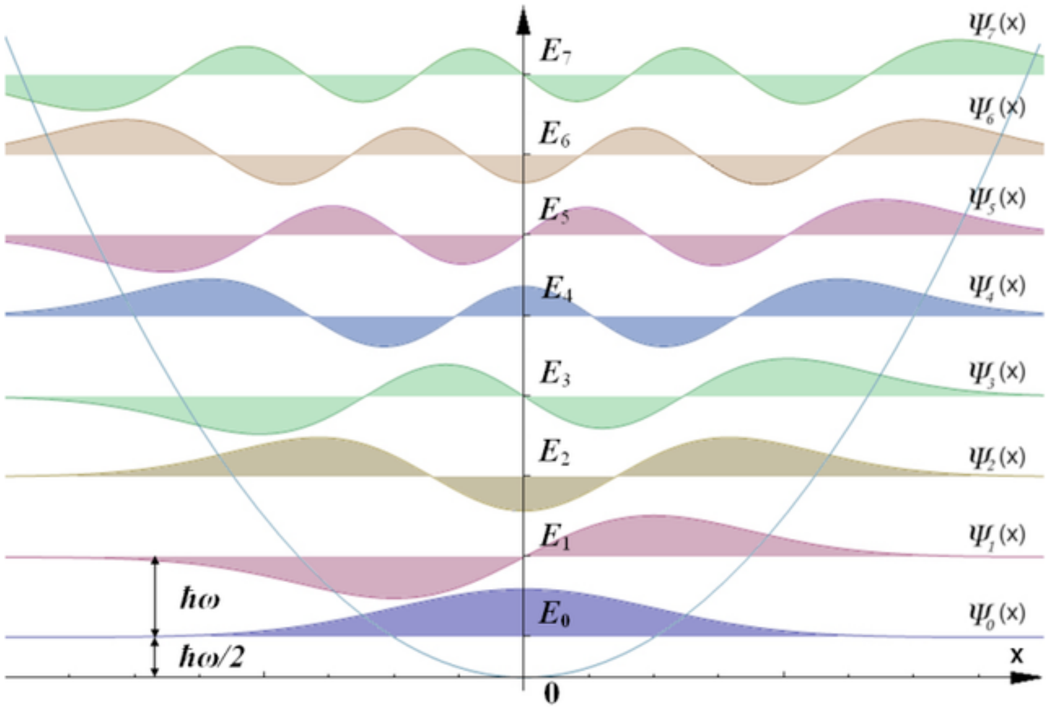


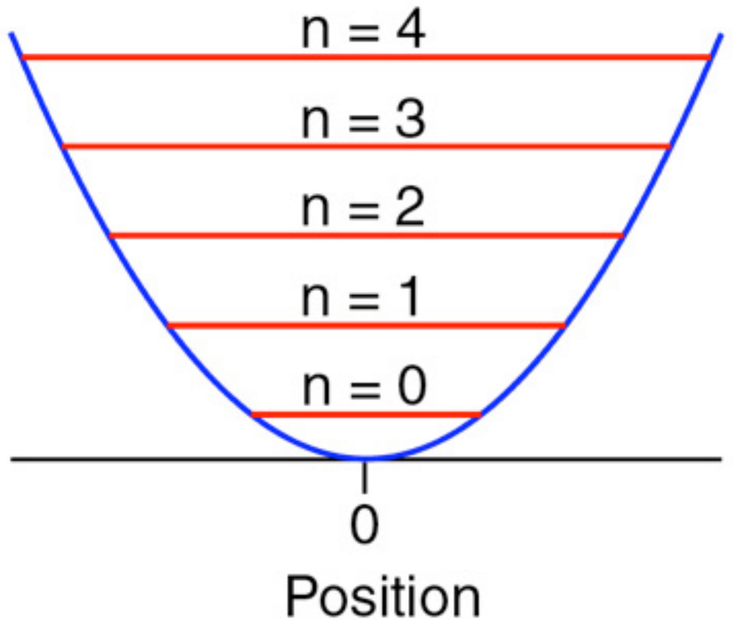
© 2012 Pearson Education, Inc.

"Standing wave". Licensed under Public Domain via Wikimedia Commons

Quantum oscillator

Standing matter wave



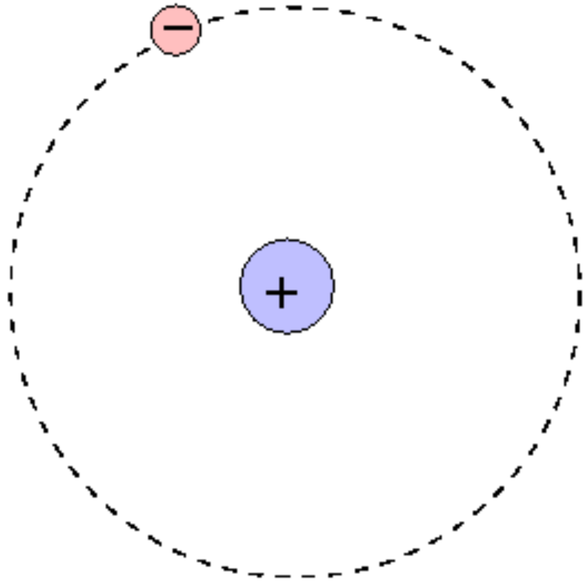


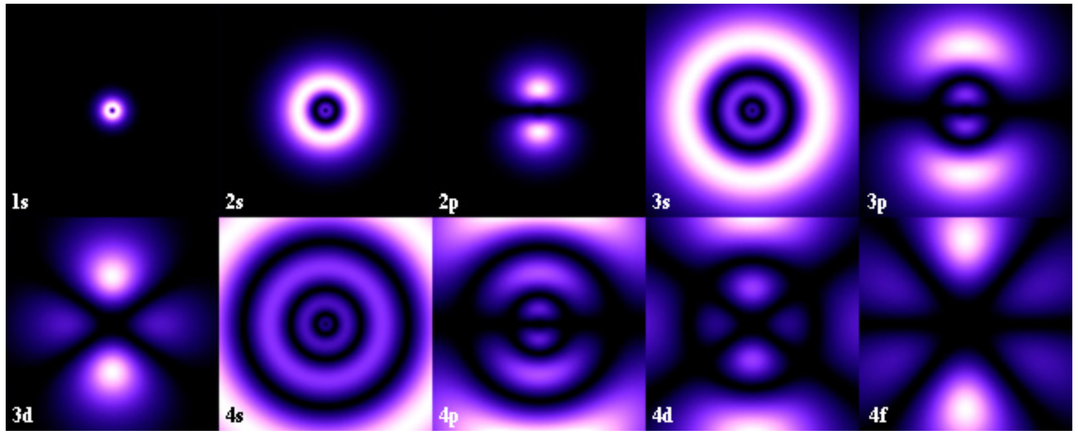
Oscillation energies are quantized in quantum physics

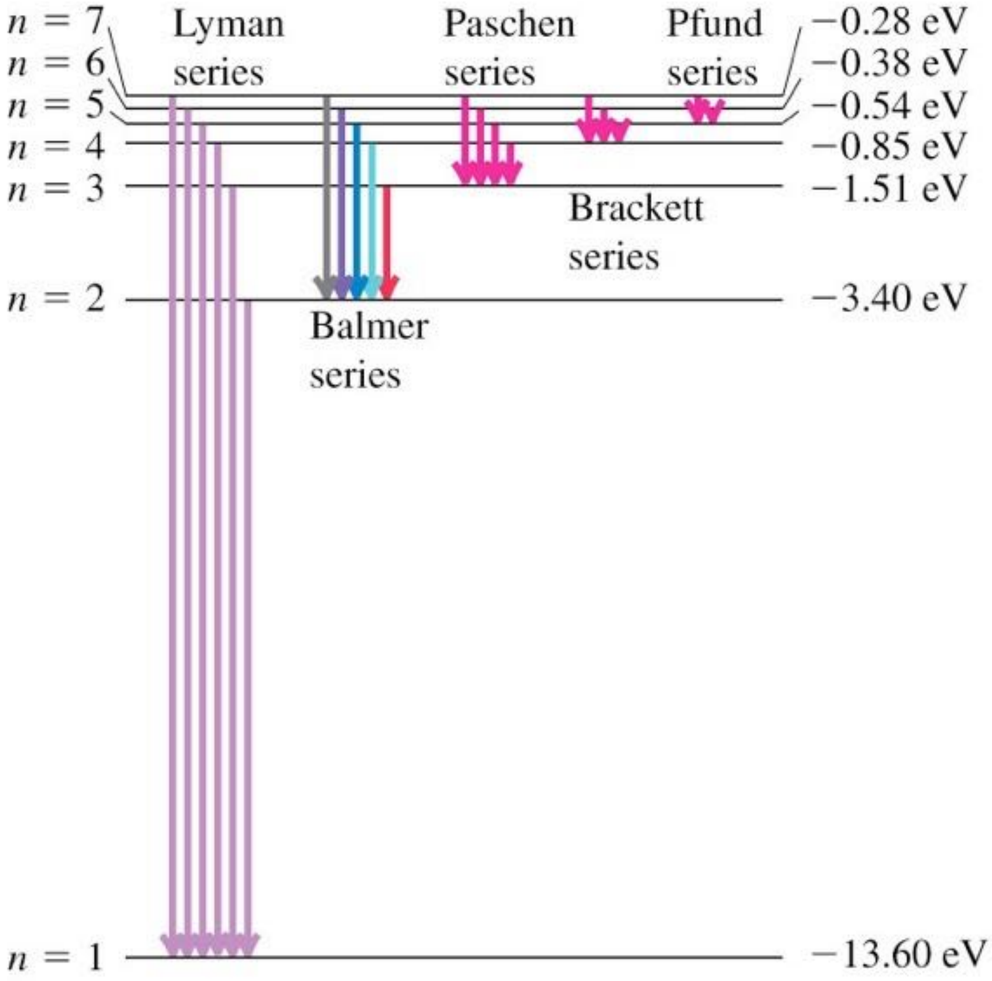
Each energy level corresponds to a standing matter wave!

Hydrogen atom

Standing matter waves lead to quantization of the allowed atomic energies





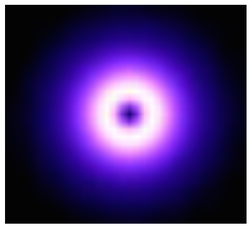


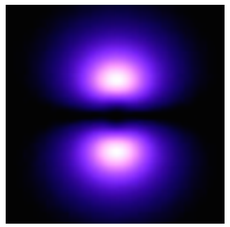
Bits vs. Quantum Bits (Qubits)

- “Classical” computer: Data is represented by bits, either 0 or 1

- Quantum computer: A quantum bit (qubit) can be in a superposition of 0 and 1, just like a classical wave:

$$\left|\text{One qubit}\right\rangle = \quad + \quad = \frac{1}{\sqrt{2}}\left(|0\rangle + |1\rangle\right)$$

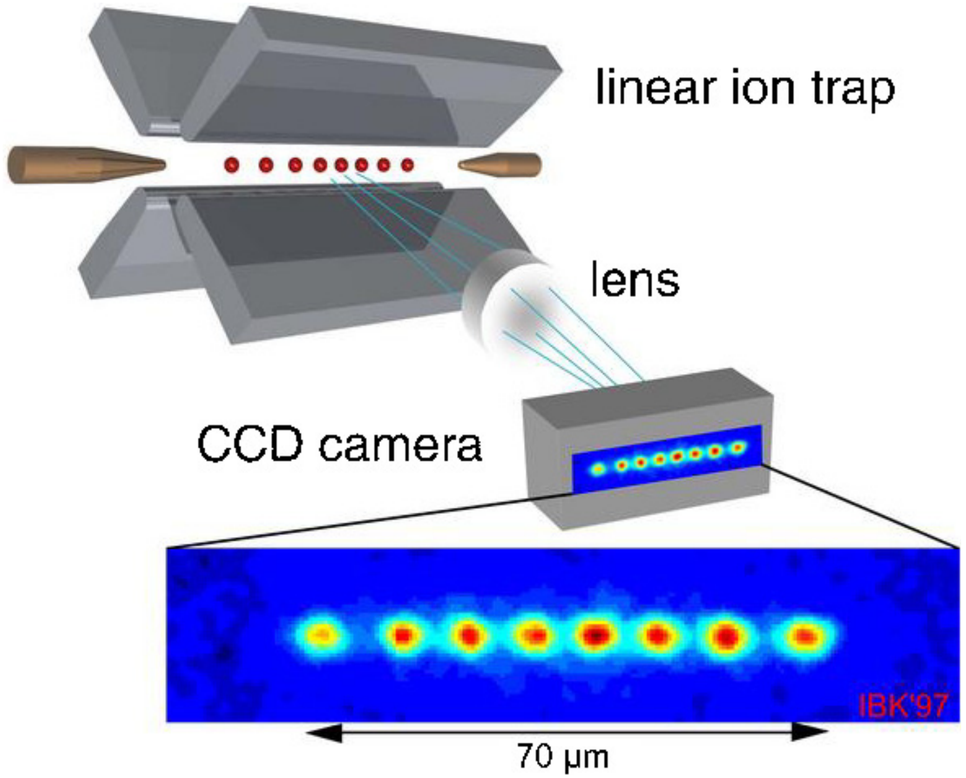




- But qubits can also be entangled (unlike anything classical):

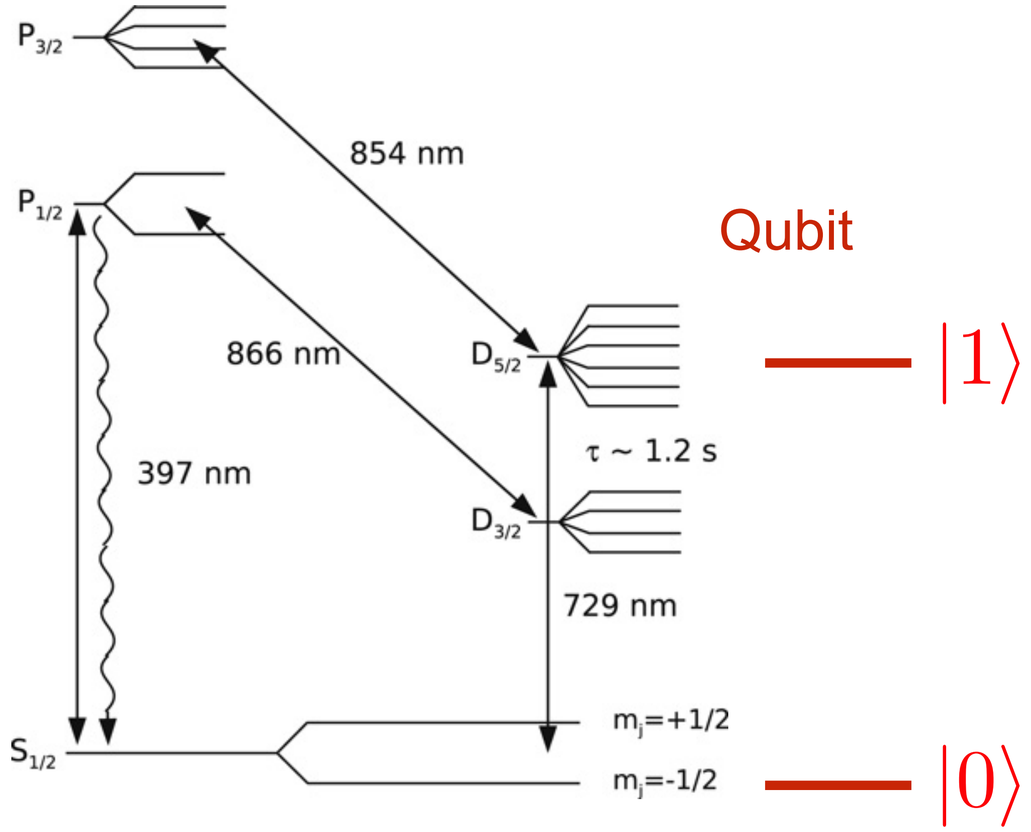
$$|\text{Two qubits}\rangle = \frac{1}{\sqrt{2}}\left(|00\rangle + |11\rangle\right)$$

Quantum computing with trapped atoms



J. J. García-Ripoll et al., “Quantum information processing with cold atoms and trapped ions”,

J. Phys. B: At. Mol. Opt. Phys. **38**, S567 (2005).



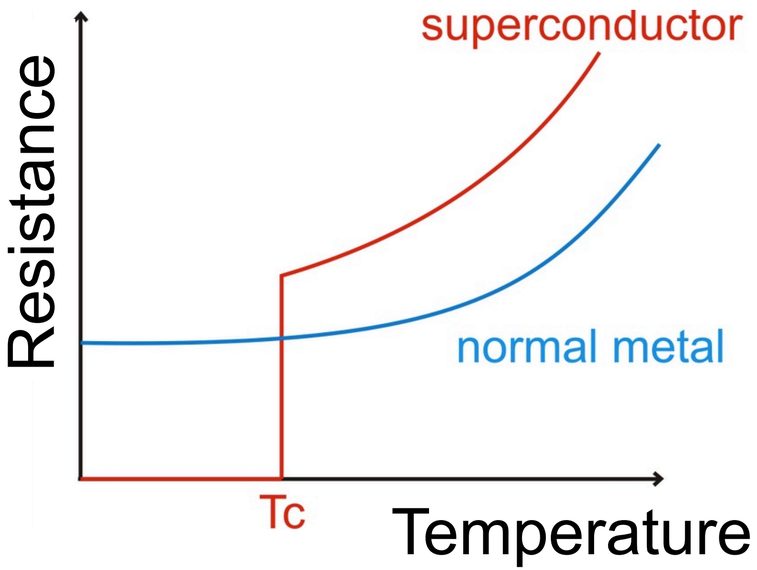
Energy levels for $^{40}Ca^{+}$

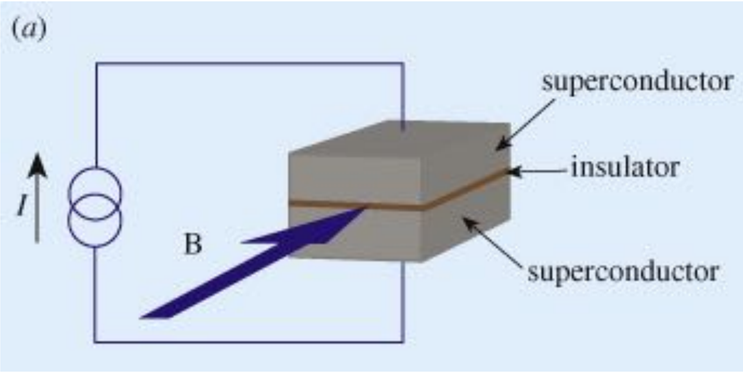
H. Häfner et al., Quantum Computing with trapped ions, Phys. Rep. 469, 155 (2008)

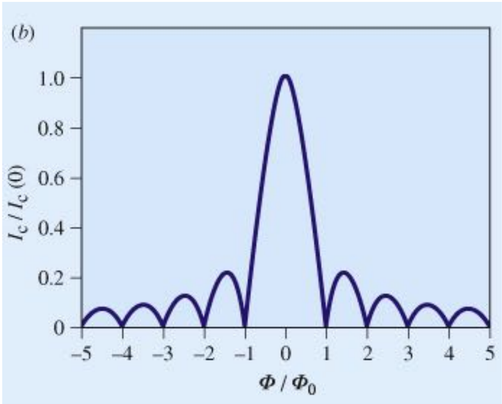
How to make qubits using electrical circuits

- Cool the circuit down until it becomes a superconductor! Aluminum wires become superconducting at temperatures below 4 Kelvin.

- Josephson junction: SC-Insulator-SC shows quantum wave interference behaviour, just like electrons going through a double-slit! It allows the design of ***artificial atoms***.



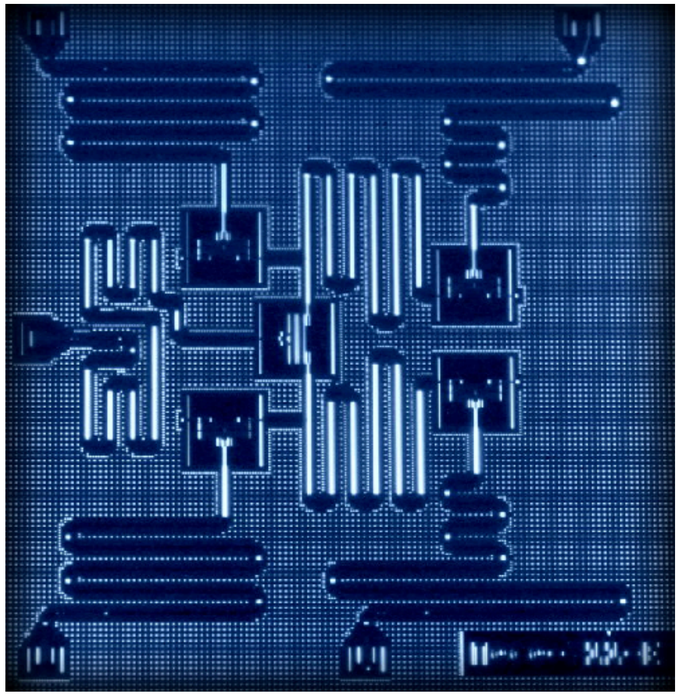




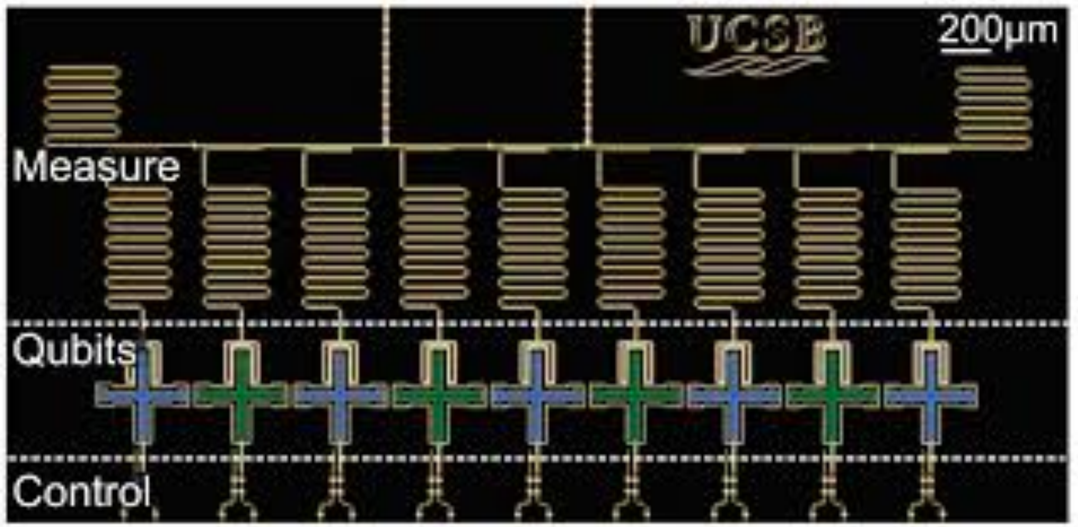
P. A. Warburton, “Josephson effect: 50 years of science and technology”, Phys. Educ. 46, 669 (2011).

IBM’s and Google’s quantum computer

Transmons connected by wires, operated at temperature = 0.01 Kelvin.



IBM’s 5-qubit
quantum computer



Google’s 9-qubit
quantum computer

Say we have n=100 logical (error corrected) qubits

- And each operation takes 10^{-7}s = 0.0000001 seconds
- Age of our universe is 10^{17}s = 10000000000000000 seconds

Problem	Runtime for best classical algorithm	Runtime for best quantum algorithm
Quantum simulation (molecules, materials,…)	10^{23} s	10^{-5} s
Solving linear systems (matrix inversion, differential eqns, …)		

Want to learn more?

- Watch a deeper version of this talk (for beginning university students) on YouTube: https://youtu.be/YwhaL2MHkhU

- For quantum computing video games and other educational activities, click here: http://quantum-bc.ca/learn/diversifying-talent-in-quantum-computing/quantum-kit/

WHAT IS A MATRIX?

NUMBERS: $1, 2, 3, 4, \ldots$

MATRIX: $\begin{pmatrix} 0 & 1 \\ 2 & 3 \end{pmatrix}$, $\begin{pmatrix} 1 & 2 & 5 \\ 3 & 4 & 6 \\ 7 & 8 & 9 \end{pmatrix}$, $\ldots$

2×2

2 COLUMNS,

2 ROWS

3×3