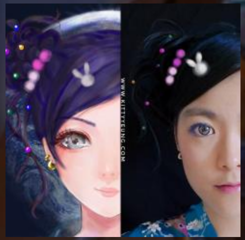
Introduction to Quantum Computing



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Microsoft

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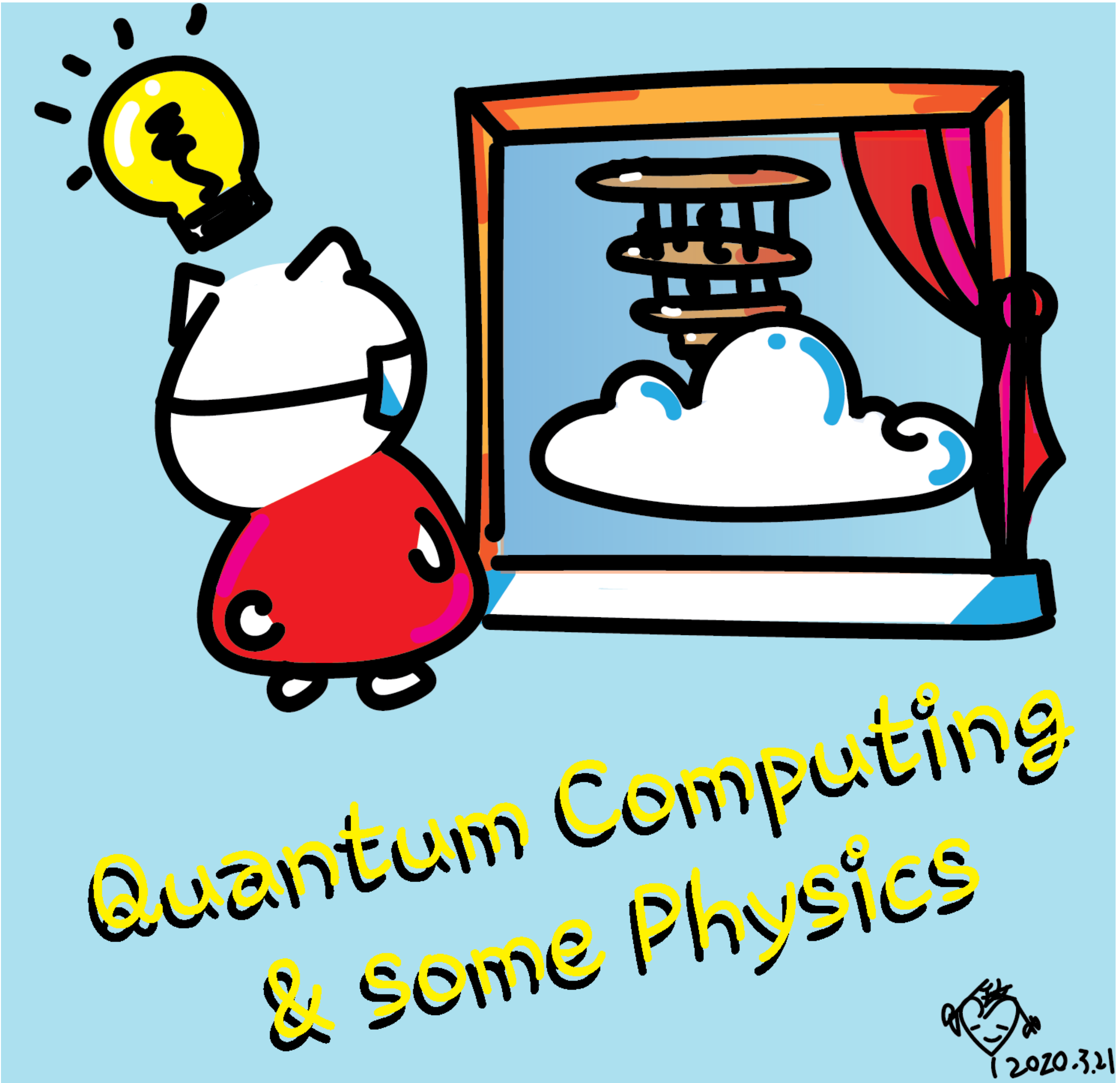
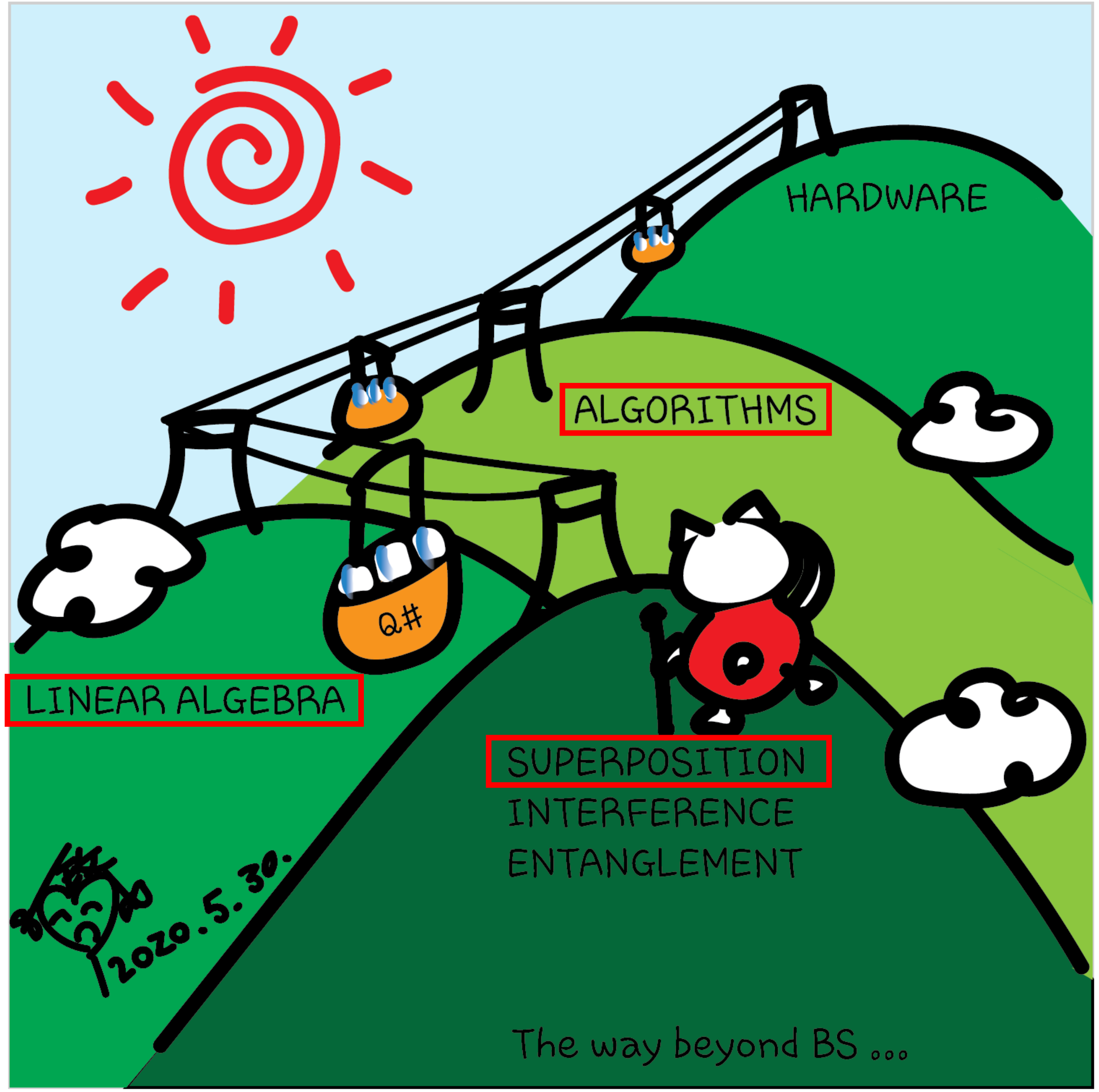
June 7, 2020
Hackaday, session 10
Other communities, session 2

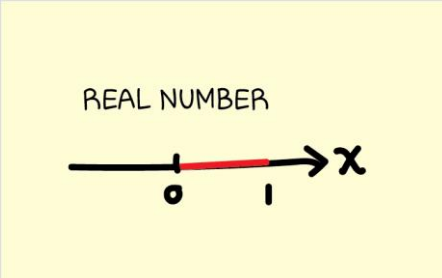
Class structure

- Comics on Hackaday – Introduction to Quantum Computing every Sun
- 30 mins – 1 hour every Sun, one concept (theory, hardware, programming), Q&A
- Contribute to Q# documentation http://docs.microsoft.com/quantum
- Coding through Quantum Katas https://github.com/Microsoft/QuantumKatas/
- Discuss in Hackaday project comments throughout the week
- Take notes

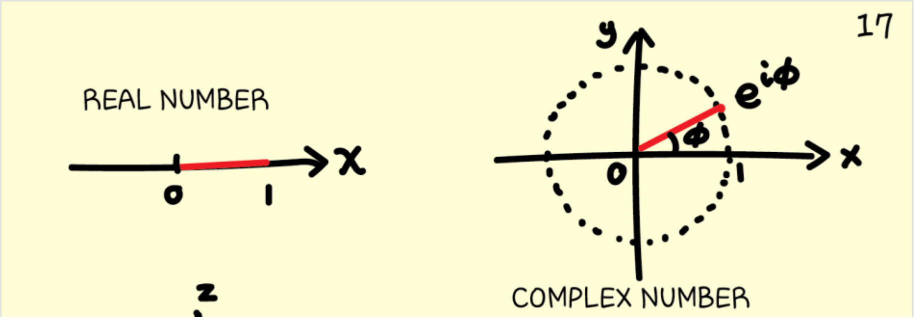



HARDWARE
ALGORITHMS
Q#
LINEAR ALGEBRA
SUPERPOSITION
INTERFERENCE
ENTANGLEMENT
2020.5.30.
The way beyond BS ...

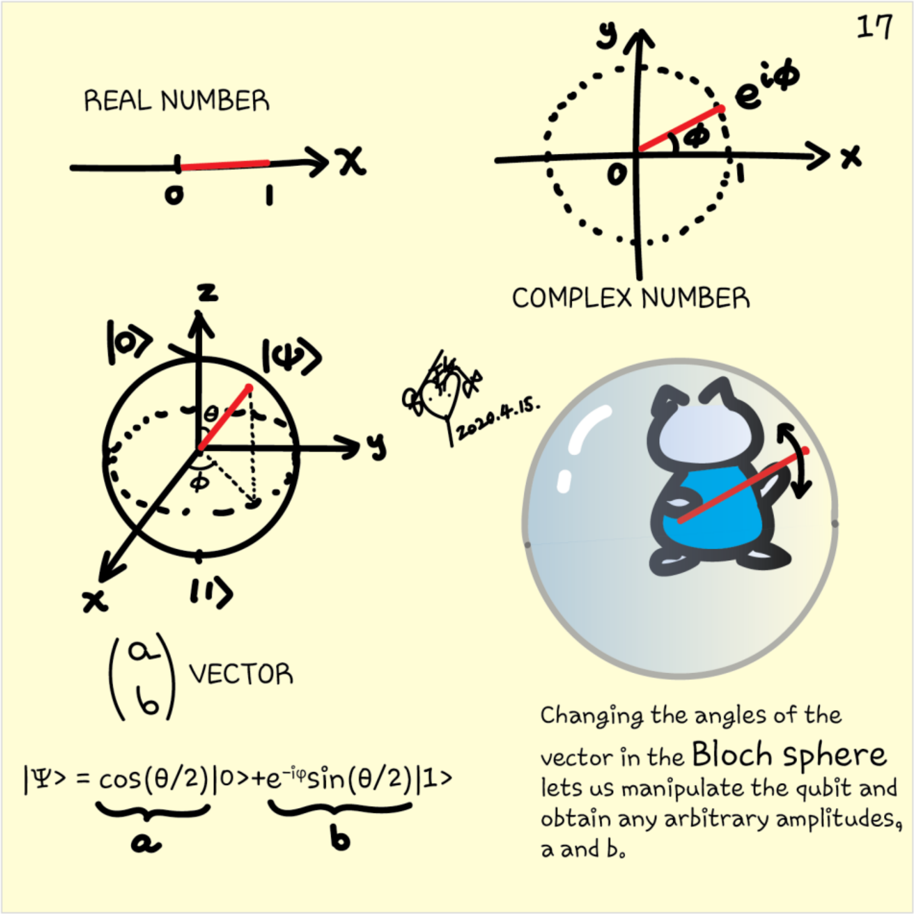
Graphic representation of a qubit



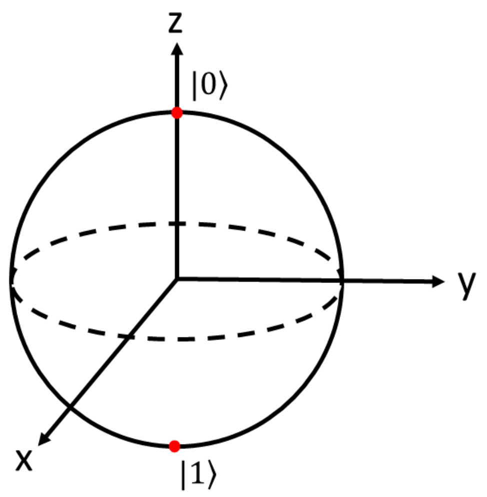
Graphic representation of a qubit

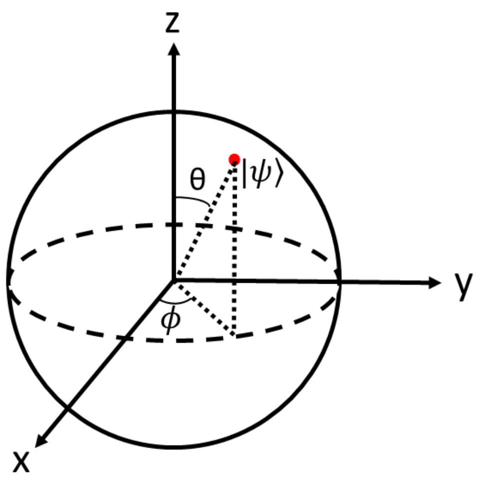


Graphic representation of a qubit



Bloch sphere



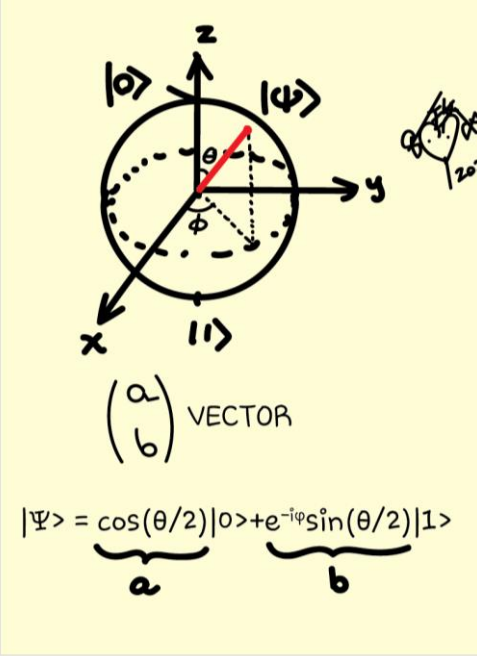


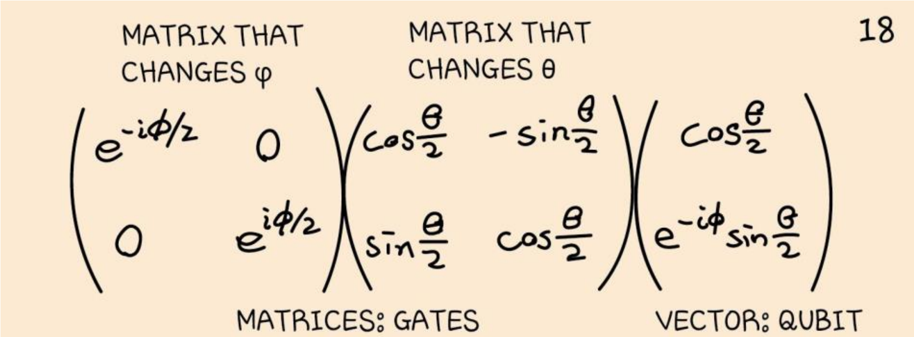
Arbitrary state

$$|\psi\rangle = \cos\frac{\theta}{2}|0\rangle + e^{-i\phi}\sin\frac{\theta}{2}|1\rangle$$

the states $|0\rangle$ and $|1\rangle$ are just two special cases with θ = 0° and 180°, respectively.

Gates (quantum operations)





General rotation

In general, rotation gates, R, about an axis can be described by the angles ϕ and θ:

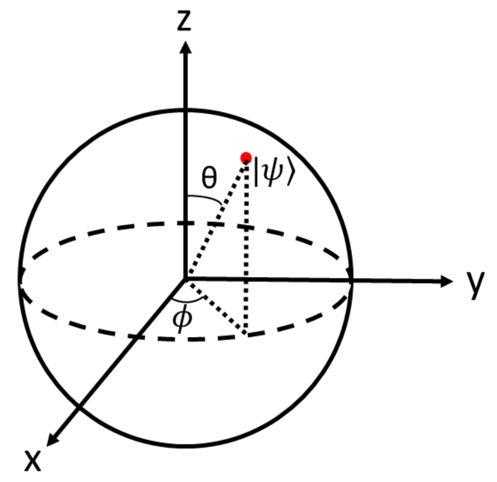
$$R_z(\phi) = \begin{bmatrix} e^{-i\phi/2} & 0 \\ 0 & e^{i\phi/2} \end{bmatrix},$$

$$R_y(\theta) = \begin{bmatrix} \cos\frac{\theta}{2} & -\sin\frac{\theta}{2} \\ \sin\frac{\theta}{2} & \cos\frac{\theta}{2} \end{bmatrix},$$

and

$$R_x(\theta) = \begin{bmatrix} \cos\frac{\theta}{2} & -i\sin\frac{\theta}{2} \\ -i\sin\frac{\theta}{2} & \cos\frac{\theta}{2} \end{bmatrix}$$

$$= R_z\left(\frac{\pi}{2}\right) R_y(\theta) R_z\left(-\frac{\pi}{2}\right).$$



https://review.docs.microsoft.com/en-us/quantum/concepts/the-qubit?branch=tensor-product

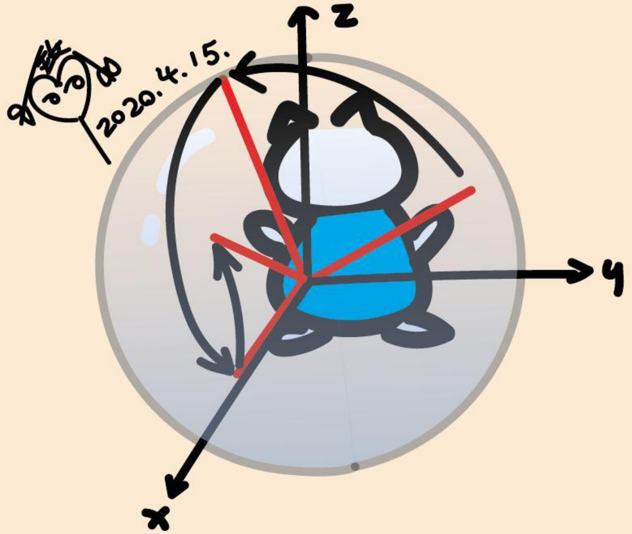
MATRIX THAT CHANGES φ

MATRIX THAT CHANGES θ

$$\begin{pmatrix} e^{-i\phi/2} & 0 \\ 0 & e^{i\phi/2} \end{pmatrix} \begin{pmatrix} \cos\frac{\theta}{2} & -\sin\frac{\theta}{2} \\ \sin\frac{\theta}{2} & \cos\frac{\theta}{2} \end{pmatrix} \begin{pmatrix} \cos\frac{\theta}{2} \\ e^{-i\phi}\sin\frac{\theta}{2} \end{pmatrix}$$

MATRICES: GATES

VECTOR: QUBIT



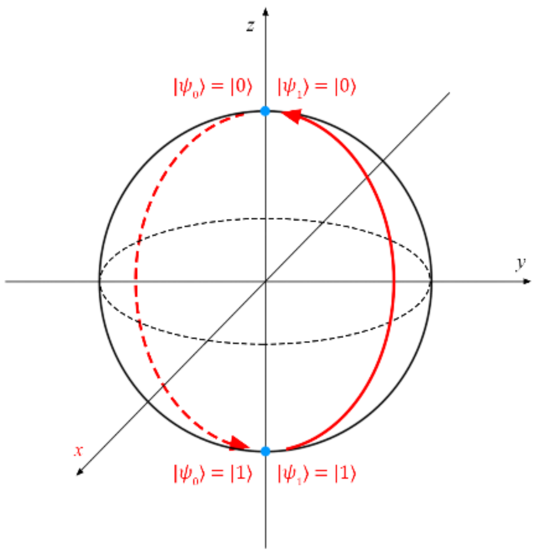
Like a set of coins, a combination of them can make up any number.

We can have a set of matrix operations (gates) that moves the qubit to anywhere on the Bloch sphere.

Pauli gates

$$X = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

$$X \begin{pmatrix} a \\ b \end{pmatrix} = \begin{pmatrix} b \\ a \end{pmatrix}$$

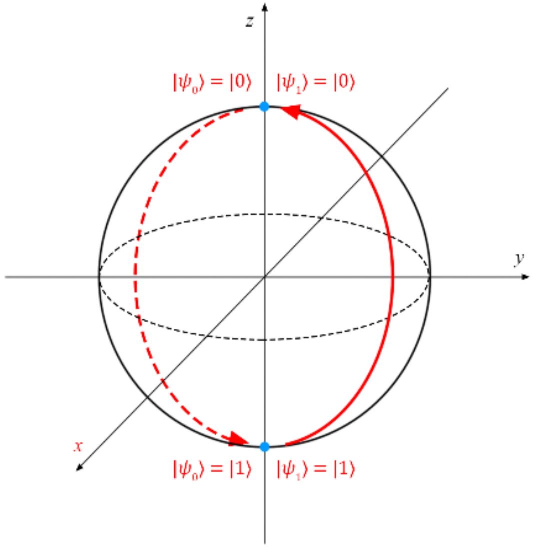


Pauli X

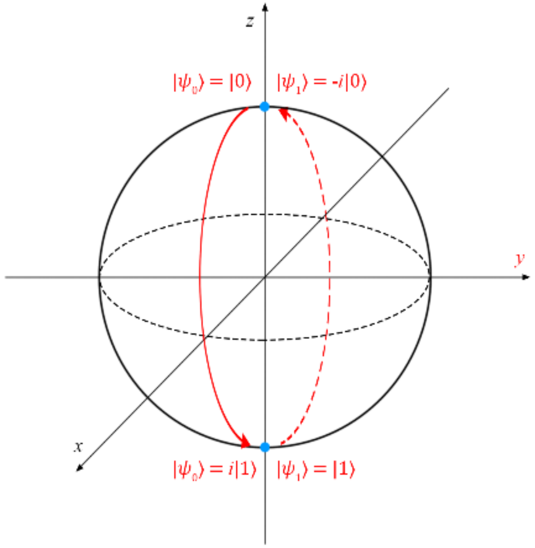
Pauli gates

$$X = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \qquad Y = \begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$$

$$X \begin{pmatrix} a \\ b \end{pmatrix} = \begin{pmatrix} b \\ a \end{pmatrix} \qquad Y \begin{pmatrix} a \\ b \end{pmatrix} = i \begin{pmatrix} -b \\ a \end{pmatrix}$$



Pauli X



Pauli Y

Pauli gates

$$X = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

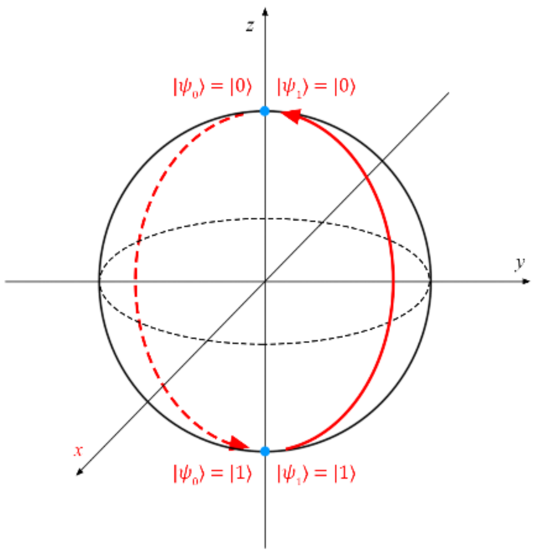
$$Y = \begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$$

$$Z = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$$

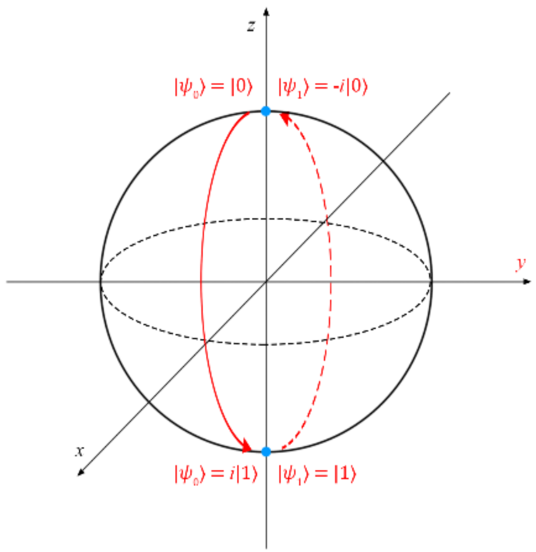
$$X \begin{pmatrix} a \\ b \end{pmatrix} = \begin{pmatrix} b \\ a \end{pmatrix}$$

$$Y \begin{pmatrix} a \\ b \end{pmatrix} = i \begin{pmatrix} -b \\ a \end{pmatrix}$$

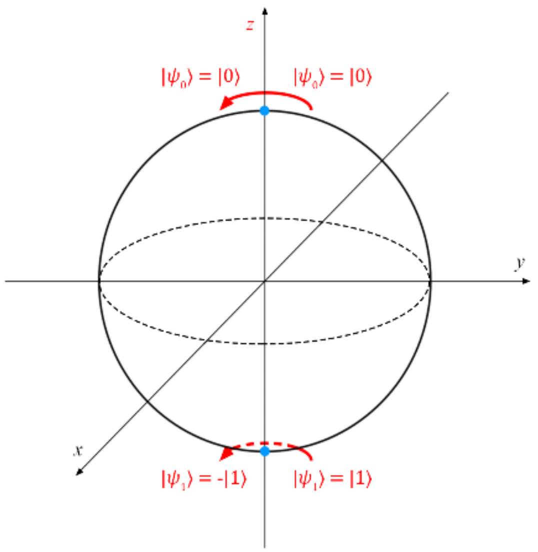
$$Z \begin{pmatrix} a \\ b \end{pmatrix} = \begin{pmatrix} a \\ -b \end{pmatrix}$$



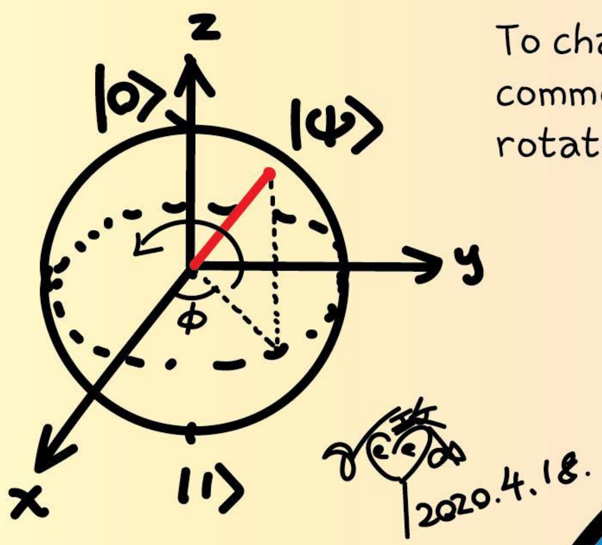
Pauli *X*



Pauli *Y*

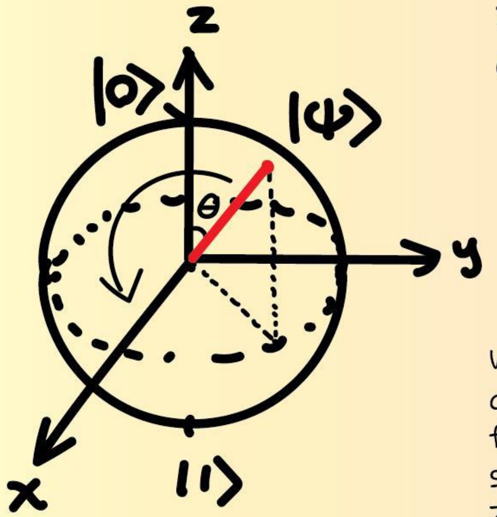


Pauli *Z*



To change the phase φ, we have a commonly used gate, Z, which rotates about the z-axis by 180°.

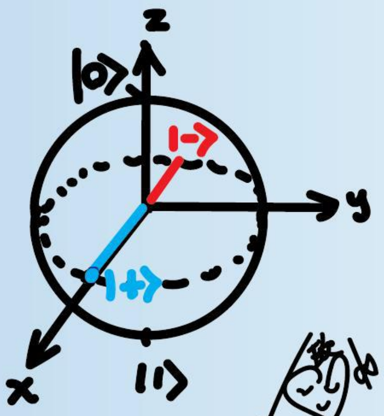
$$Z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$



Similarly, the X gate rotates about the x-axis by 180°, rotating the angle θ e.g. $X|0\rangle = |1\rangle$, $X|1\rangle = |0\rangle$.

$$X = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

We have seen in page 18 the two matrices for changing φ and θ in arbitraty amounts. They form a universal gate set - they can put a state anywhere on the Bloch Sphere. The gates Z and X are special cases of them.



Another important gate is the H (or Hadamard) gate. It changes states |0> and |1> and creates two new states in between them:

$$H|0\rangle = |+\rangle = (|0\rangle + |1\rangle)/\sqrt{2}$$

$$H|1\rangle = |-\rangle = (|0\rangle - |1\rangle)/\sqrt{2}$$

$$H = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$

And some other commonly used gates:

$$S = \sqrt[2]{Z} = \begin{pmatrix} 1 & 0 \\ 0 & i \end{pmatrix}$$ Rotates about z-axis by 90°

$$T = \sqrt[4]{Z} = \begin{pmatrix} 1 & 0 \\ 0 & e^{i\pi/4} \end{pmatrix}$$ Rotates about z-axis by 45°

$$R8 = \sqrt[8]{Z} = \begin{pmatrix} 1 & 0 \\ 0 & e^{i\pi/8} \end{pmatrix}$$ Rotates about z-axis by 22.5°

But these are all for a single qubit. What about gates for multiple qubits?

Hadamard H

$$H = \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \end{bmatrix}$$

Hadamard H

$$H = \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \end{bmatrix}$$

$$H|0\rangle = \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \end{bmatrix} \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

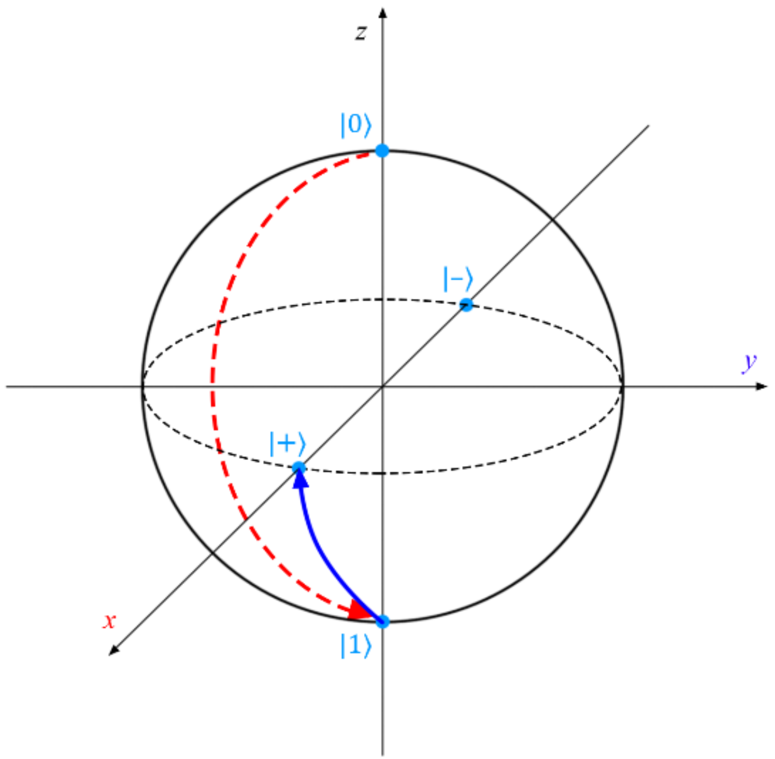
$$= \begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 0 \end{pmatrix} + \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

$$= \frac{1}{\sqrt{2}} (|0\rangle + |1\rangle) \equiv |+\rangle$$

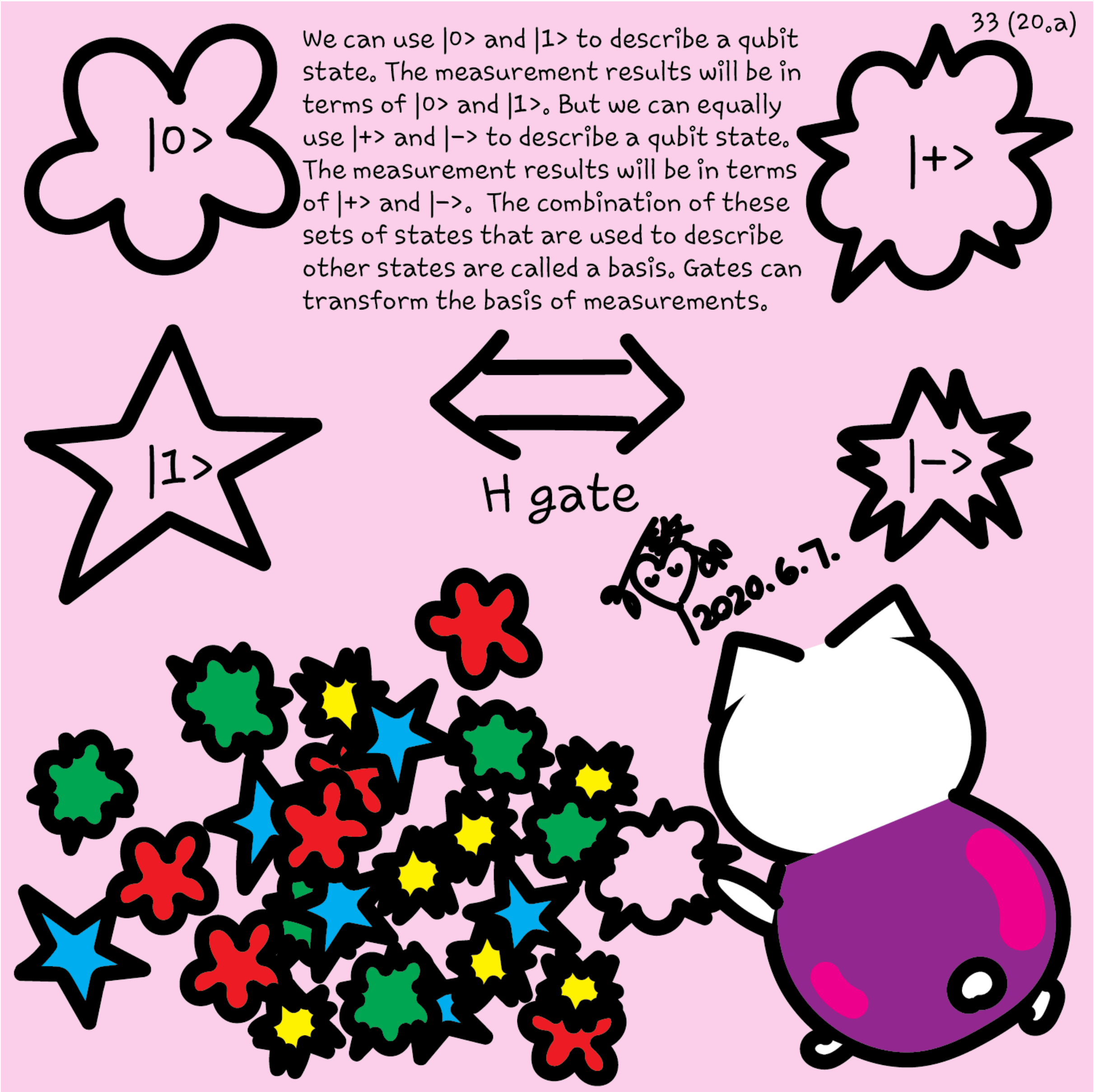
$$H|1\rangle = \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \end{bmatrix} \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

$$= \frac{1}{\sqrt{2}} (|0\rangle - |1\rangle) \equiv |-\rangle \, .$$

Hadamard revisit



$H|0\rangle = |+\rangle$



Q# exercise:

Option 1: No installation, web-based Jupyter Notebooks

- The Quantum Katas project (tutorials and exercises for learning quantum computing) https://github.com/Microsoft/QuantumKatas
- **BasicGates**
- Tasks 1.1-1.3
- Task 1.4 (p9), 1.5 (p15)
- Task 1.6, Microsoft.Quantum.Intrinsic

https://review.docs.microsoft.com/en-us/qsharp/api/qsharp/microsoft.quantum.intrinsic

- Task 1.7 (p5) Microsoft.Quantum.Math
- Tutorial https://github.com/microsoft/QuantumKatas/tree/master/tutorials/SingleQubitGates

For certificate 1

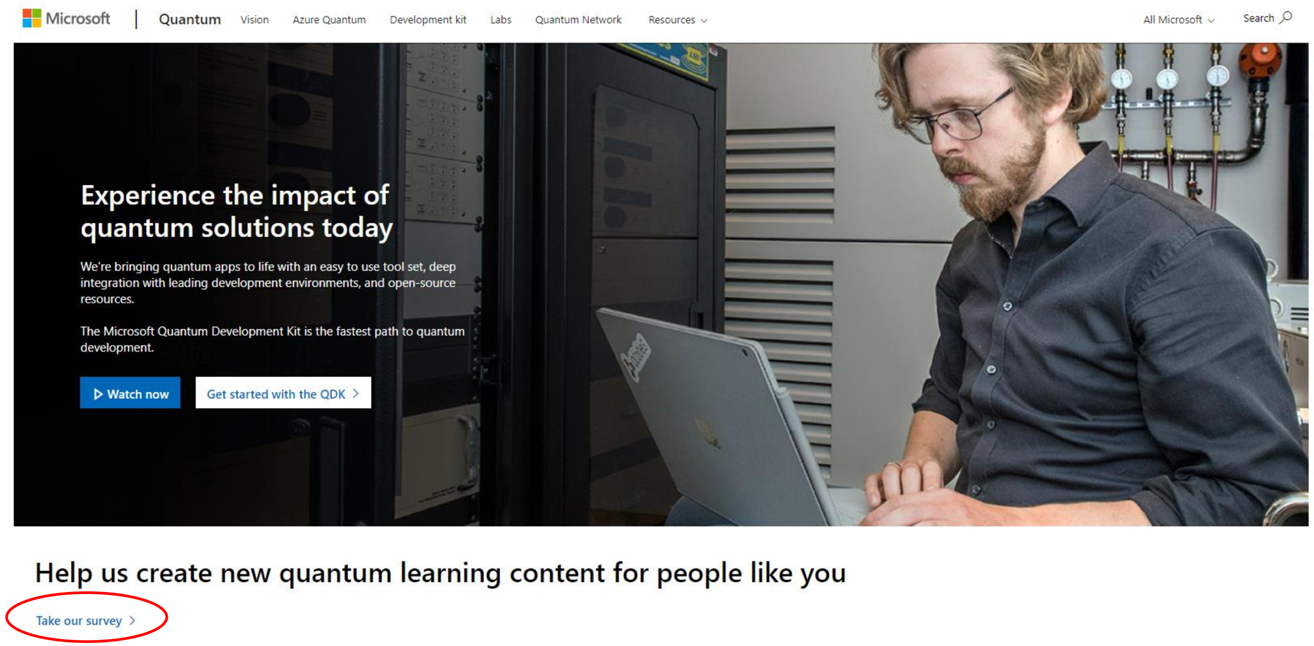
- Complete any one quantum kata
- Take a screenshot or photo
- Post on Twitter or LinkedIn
- Tag the following
- **Twitter:** @KittyArtPhysics @MSFTQuantum @QSharpCommunity #QSharp #QuantumComputing #comics #physics
- **LinkedIn:** @Kitty Y. M Yeung #MSFTQuantum #QSharp #QuantumComputing #comics #physics

Participate

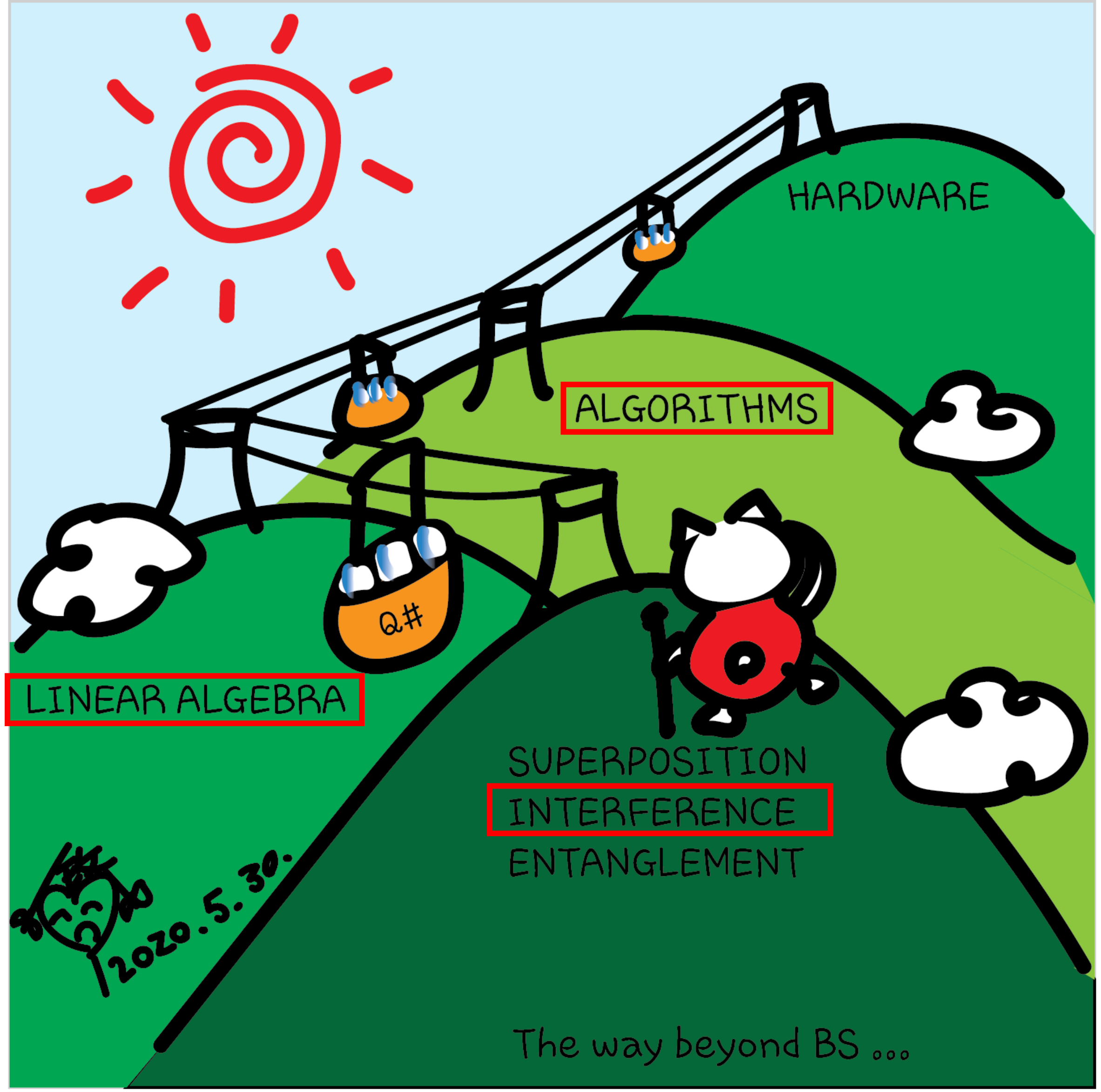
- Dr. Sarah Kaiser is doing Q# coding live every Wed and Sat at 12pm PT. Check them out! https://www.twitch.tv/crazy4pi314

- Microsoft Q# coding contest is happening from June 19 to June 22, 2020. Register now! https://codeforces.com/blog/entry/77614 aka.ms/learnqc

https://www.microsoft.com/quantum/development-kit



Next class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The way beyond BS ...

Questions

- Post in chat or on Hackaday project https://hackaday.io/project/168554-introduction-to-quantum-computing

- Past Recordings on Hackaday project or my YouTube https://www.youtube.com/c/DrKittyYeung