บทที่ 4 INTRO TO QUANTUM COMPUTING

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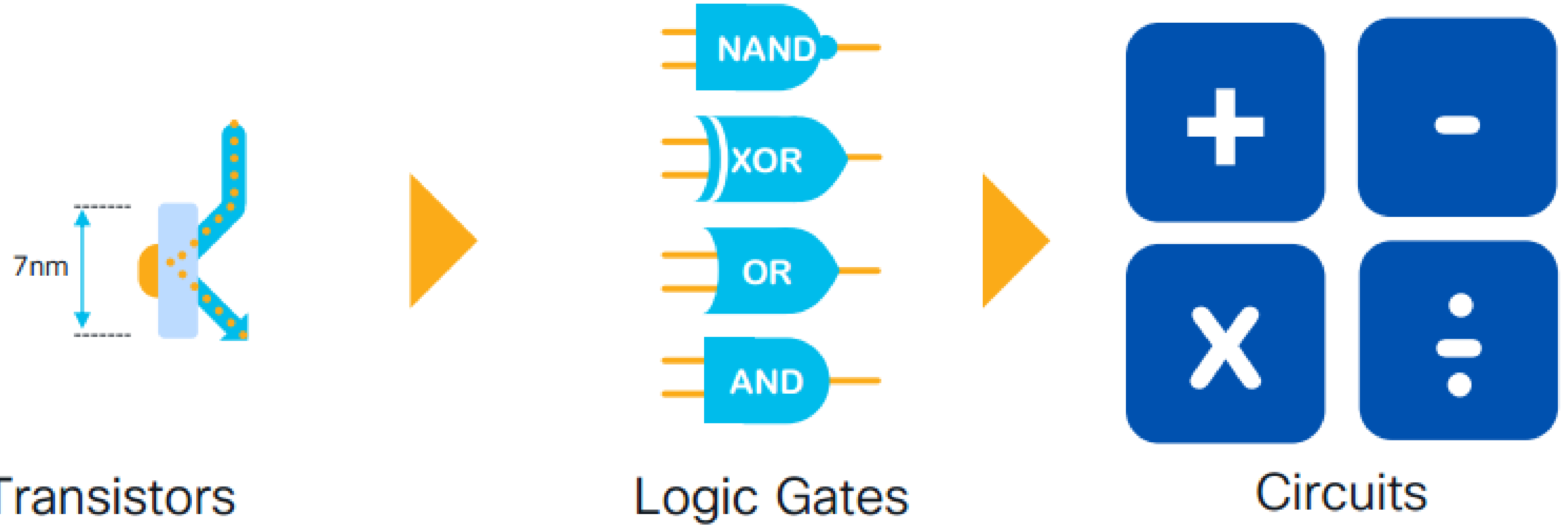
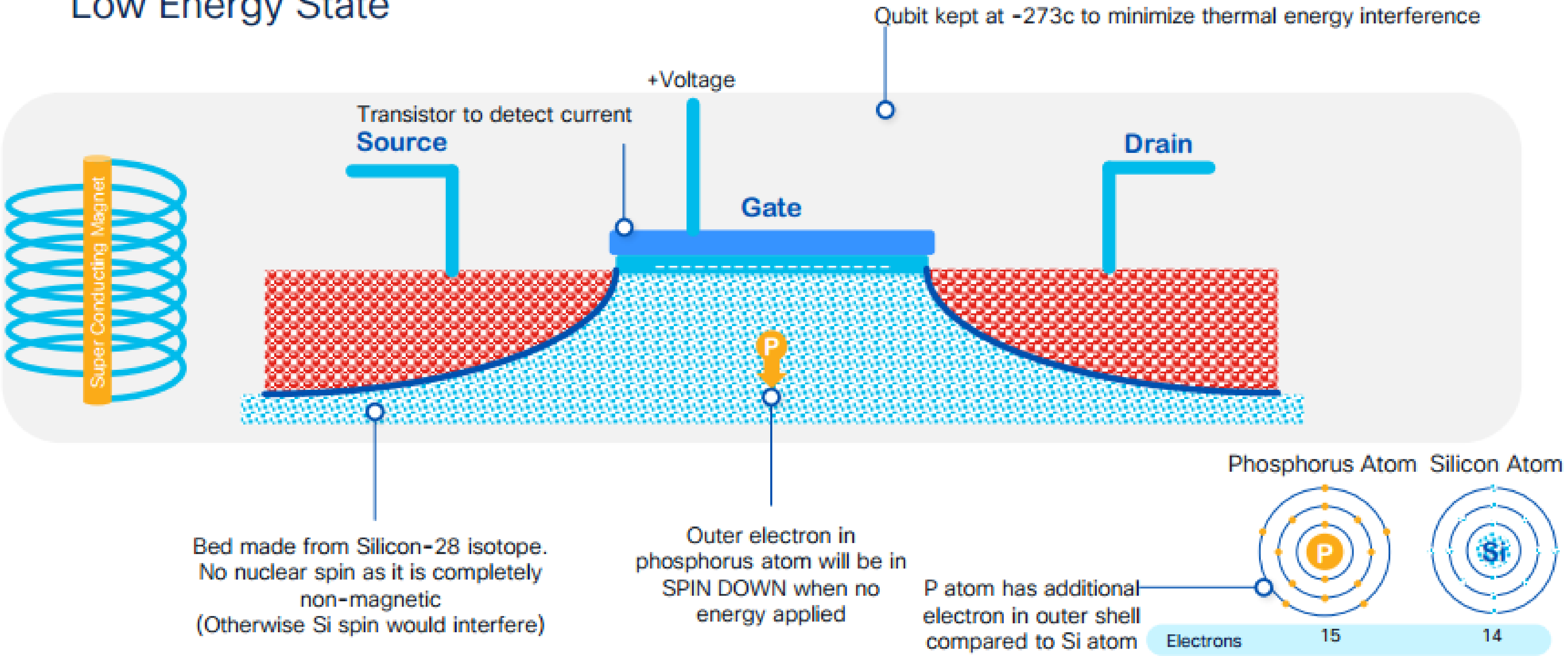
คณะวิทยาศาสตร์และเทคโนโลยี มหาวิทยาลัยสวนดุสิต

Digital Circuits Quick Recap



Anatomy of a Compute Qubit

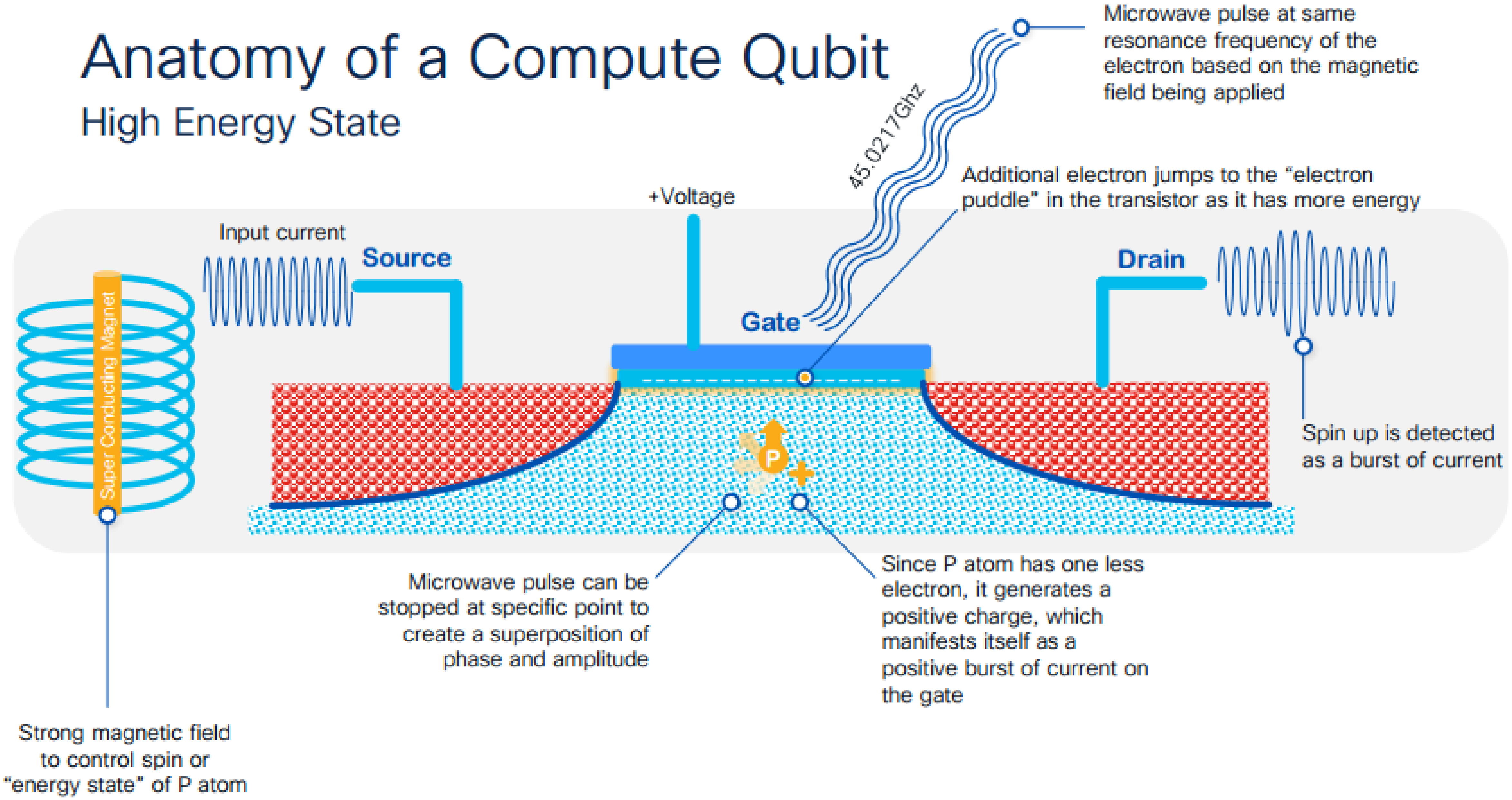
Low Energy State



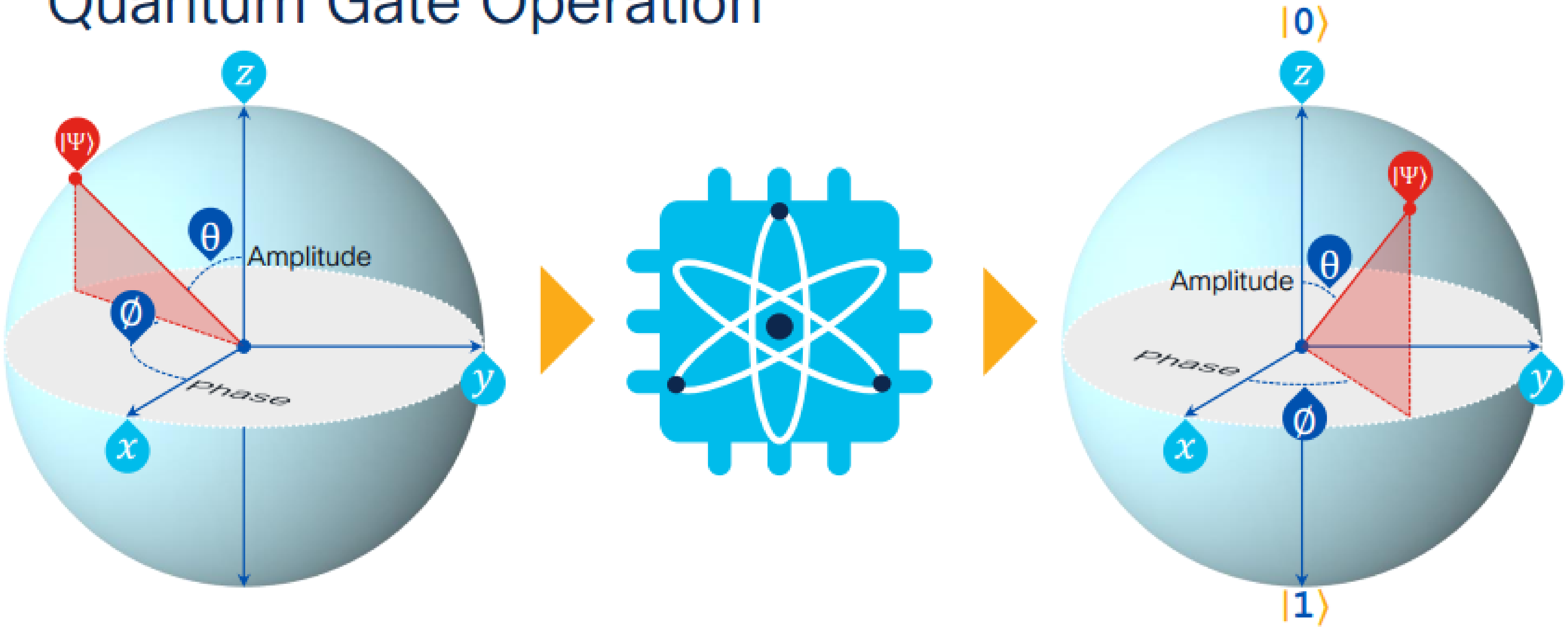
	Phosphorus Atom	Silicon Atom
Electrons	15	14
Protons	15	14
Neutrons	16	14

Anatomy of a Compute Qubit

High Energy State



Quantum Gate Operation



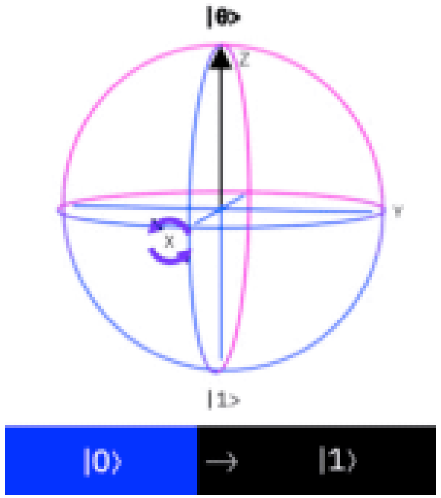
Quantum Gates :

- manipulate Amplitude θ and Phase Φ of the state vector
- take superpositions as inputs, rotate their probabilities, and produce *another* superposition as outputs

Quantum Gate Examples

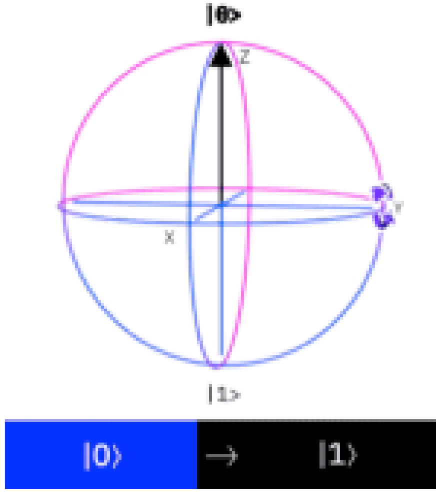
X

Pauli-X Gate is a NOT operation. It will turn a spin-up state to a spin-down and visa versa.



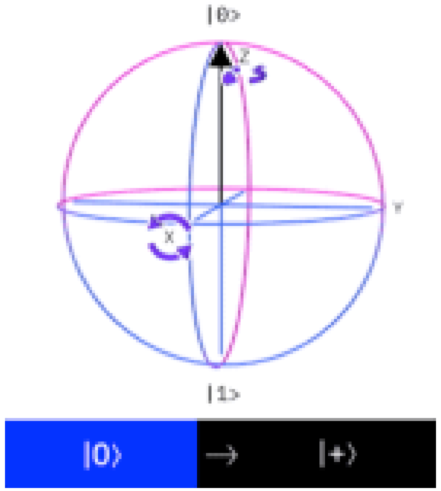
Y

Y-gate rotates around the Y-axis. It is similar to the X-gate but different in phase.



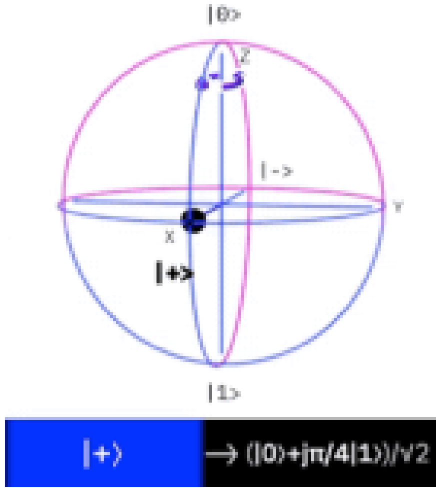
H

Hadamard Gate sets the qubit into a superposition state of a 50/50 chance that it will end up as |0> or |1>.

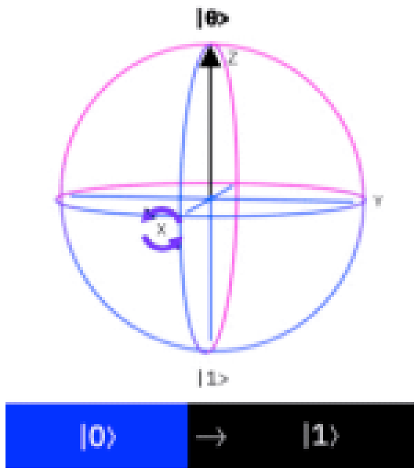


T

T gate rotates a qubit Π/4 around the z-axis.



Quantum NOT Gate Example (Pauli-X Gate)

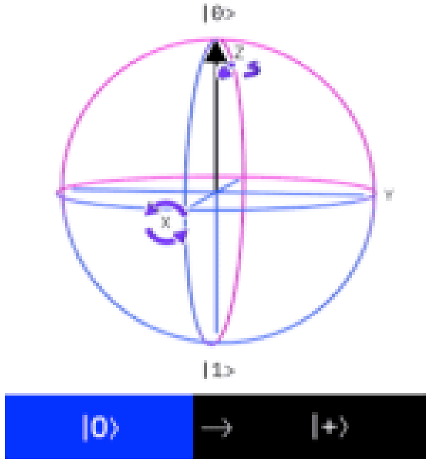


MATRIX | VECTOR | Row x Column

$$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix} \quad \begin{matrix} \blacktriangleright\ 0 \times 1 + 1 \times 0 = 0\ \blacktriangleright \\ \blacktriangleright\ 1 \times 1 + 0 \times 0 = 1\ \blacktriangleright \end{matrix} \quad \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

NOT Gate | Basis State $|0\rangle$ | Basis State $|1\rangle$

Hadamard Gate Example (Set to 50/50 State)



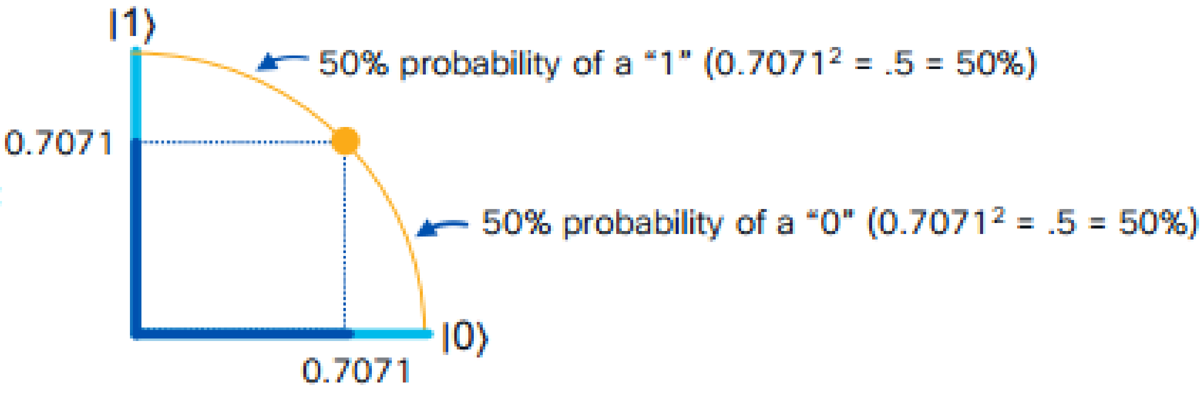
$$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\ 1 & -1\end{bmatrix}\begin{bmatrix}1\\ 0\end{bmatrix} \blacktriangleright \begin{bmatrix}.7071|0\rangle\\ .7071|1\rangle\end{bmatrix}$$

MATRIX: Hadamard Gate | VECTOR: Basis State 0 | Uniform Super Position

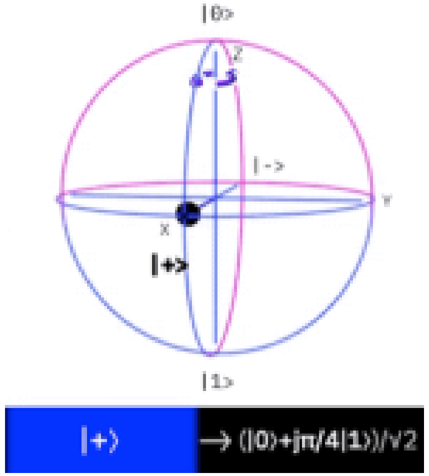
$$|\psi\rangle = \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$

$$|\psi\rangle = 0.7071|0\rangle + 0.7071|1\rangle =$$

Sums of the squares of probabilities must equal 1



T Gate Example (Rotate $\pi/4$ around the Z-axis)



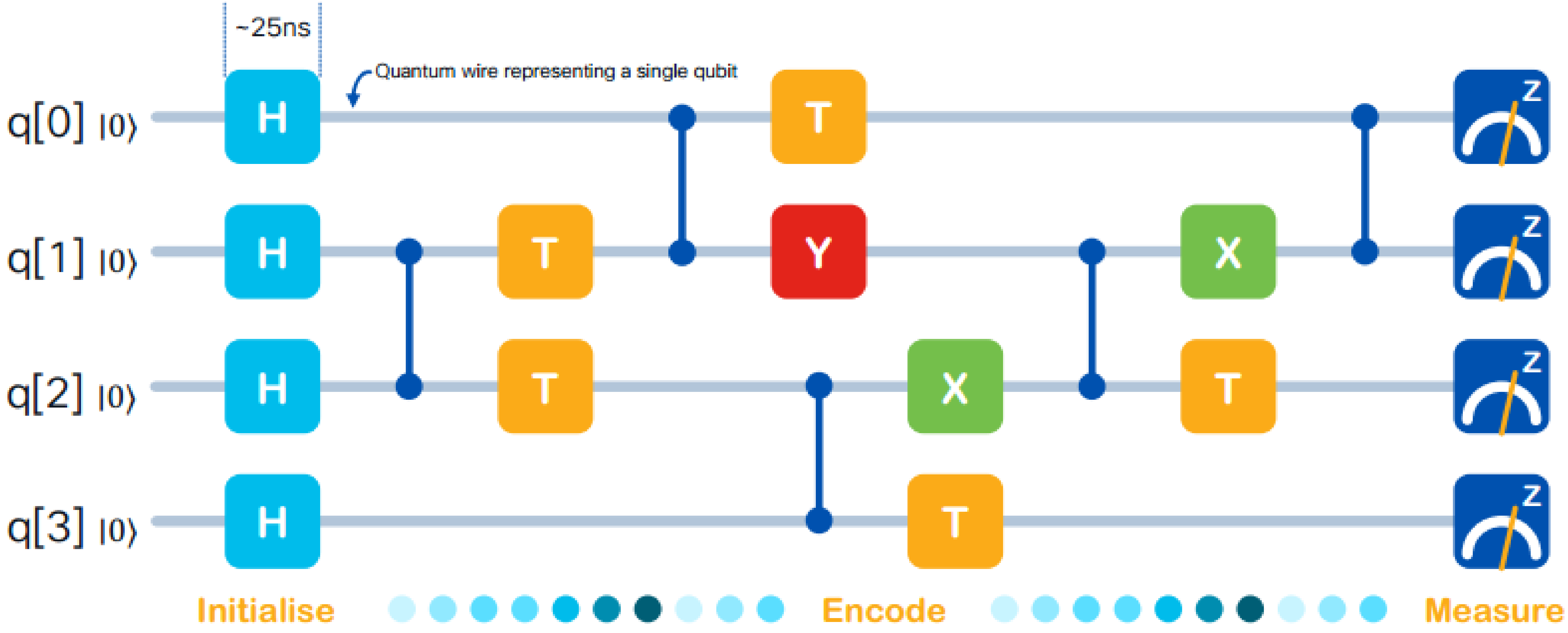
MATRIX **VECTOR**

$$\begin{bmatrix} 1 & 0 \\ 0 & e^{i\pi/4} \end{bmatrix} \begin{bmatrix} \alpha \\ \beta \end{bmatrix} \blacktriangleright \begin{bmatrix} \alpha|0\rangle \\ e^{i\pi/4}\beta|1\rangle \end{bmatrix}$$

T Gate — Basis State — Rotated position

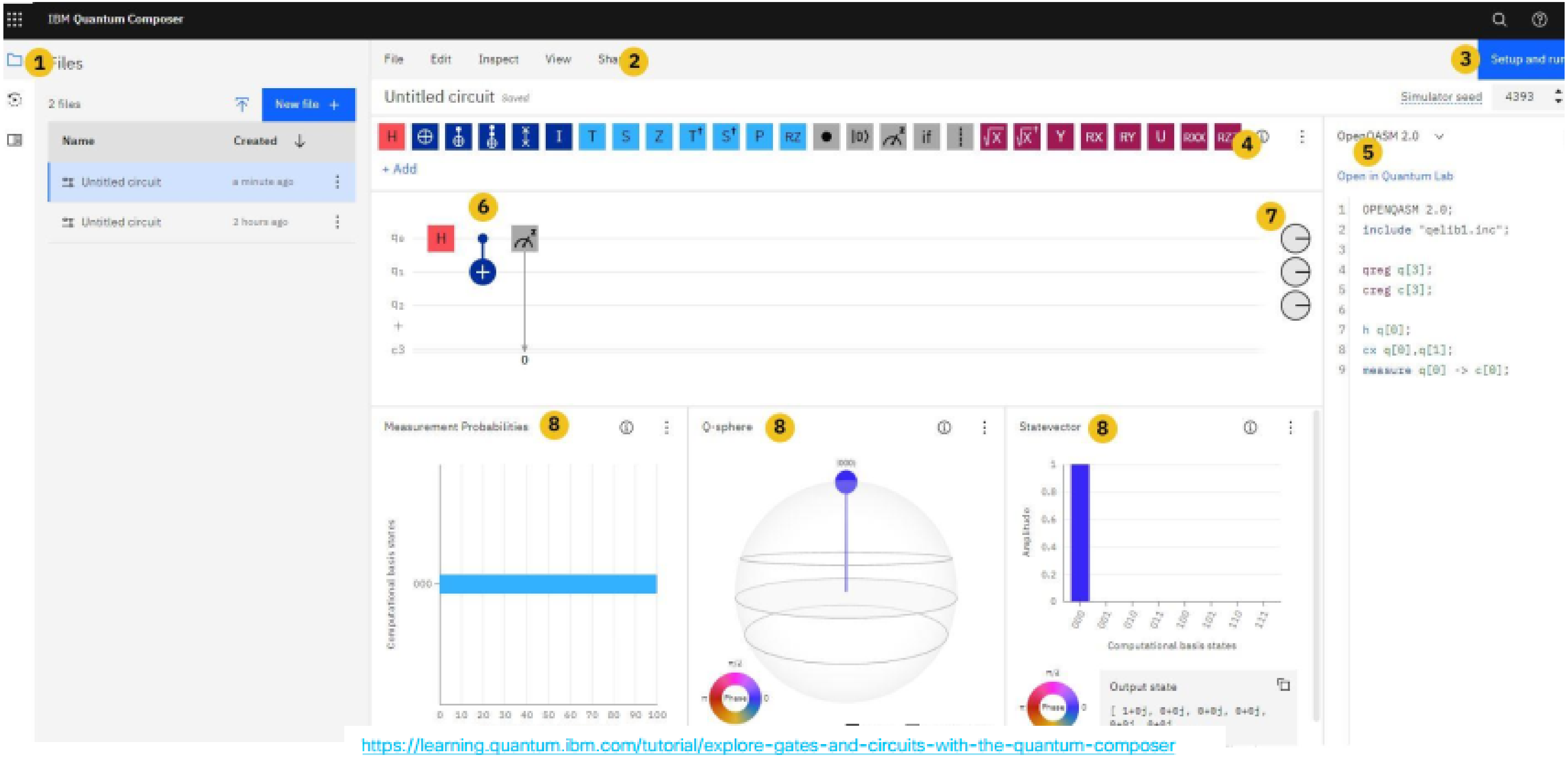
Quantum Circuits

Include Both Quantum Operators + Classical Computing



Number of input Qubits must match number of output Qubits

IBM Quantum Composer



https://learning.quantum.ibm.com/tutorial/explore-gates-and-circuits-with-the-quantum-composer

Quantum Parallelism

QUBIT #1

Holds & operates on **values** of 0 and 1 *simultaneously*

QUBIT #1 QUBIT #2

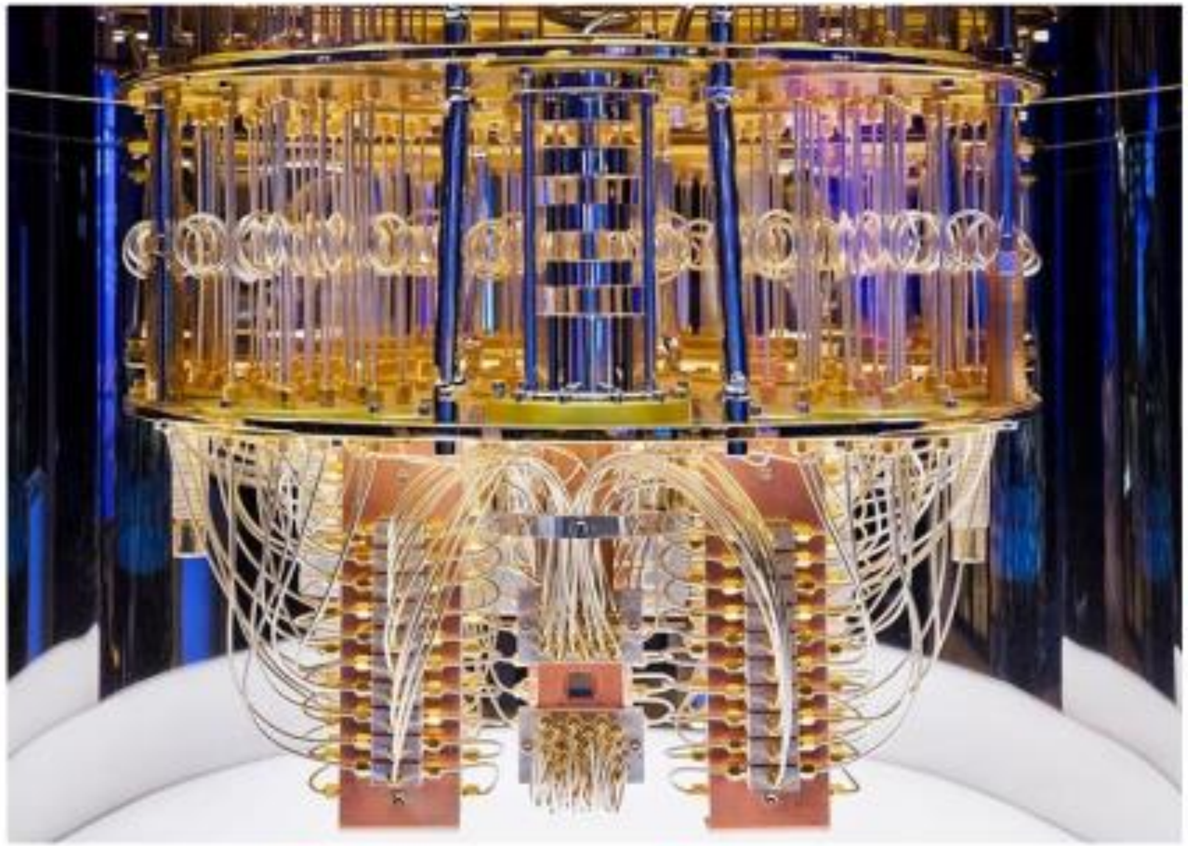
Holds & operates on **values** of 00, 01, 10, 11 *simultaneously*

QUBIT #1 QUBIT #2 QUBIT #3

Holds & operates on **values** of 000, 001, 010, 011, 100, 101, 110, 111 *simultaneously*

How Much Faster is a Quantum Computer?

- In 2021, the world's largest quantum computer had 127 Qubits
- This machine was **158M** times faster than its classic counterpart
- Example Task Execution Times:
  - Classic Computer: 2,500 years
  - Quantum Computer: **1 minute**

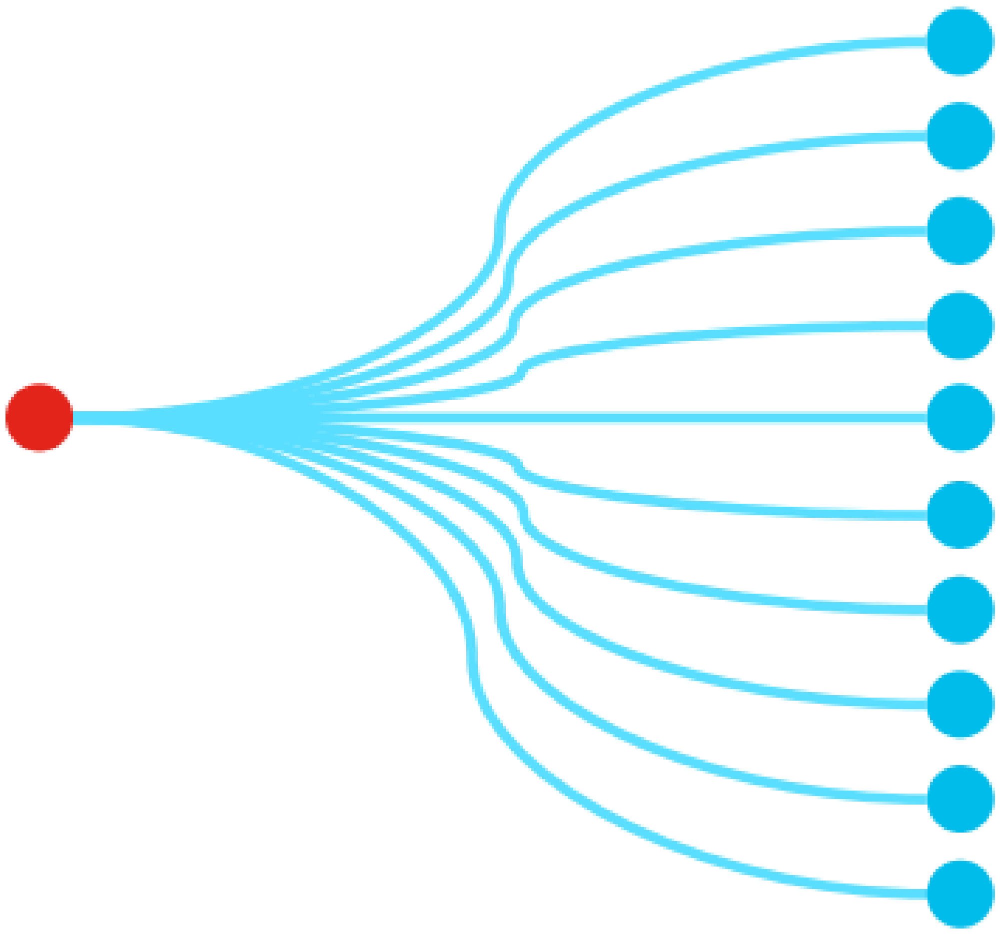


$2^{127} = 1.7 \times 10^{38}$ values

170,000,000,000,000,000,000,000,000,000,000,000,000

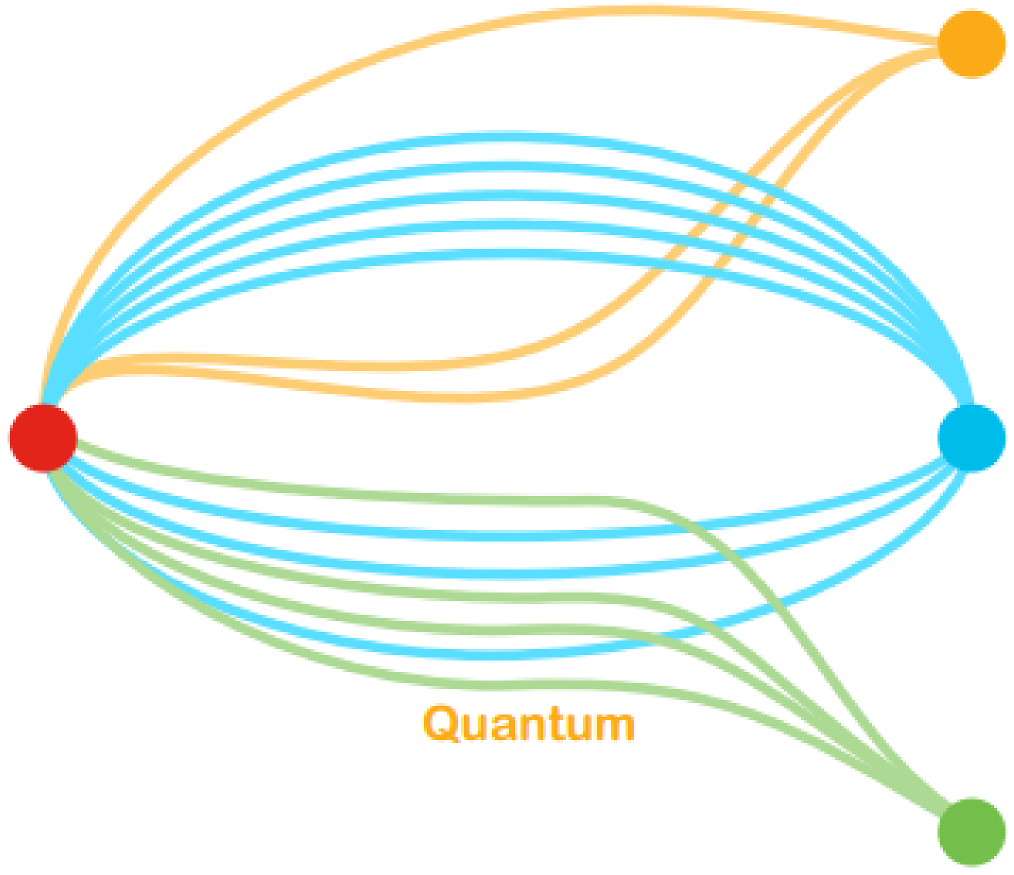
Classical Computing Problem Solving

- A classic computer needs to sequentially iterate through a problem until the correct result is found



Quantum Computing Problem Solving

- Quantum computing can provide a single or small number of answers with the highest probability of being correct, which narrows down the search for the correct solution



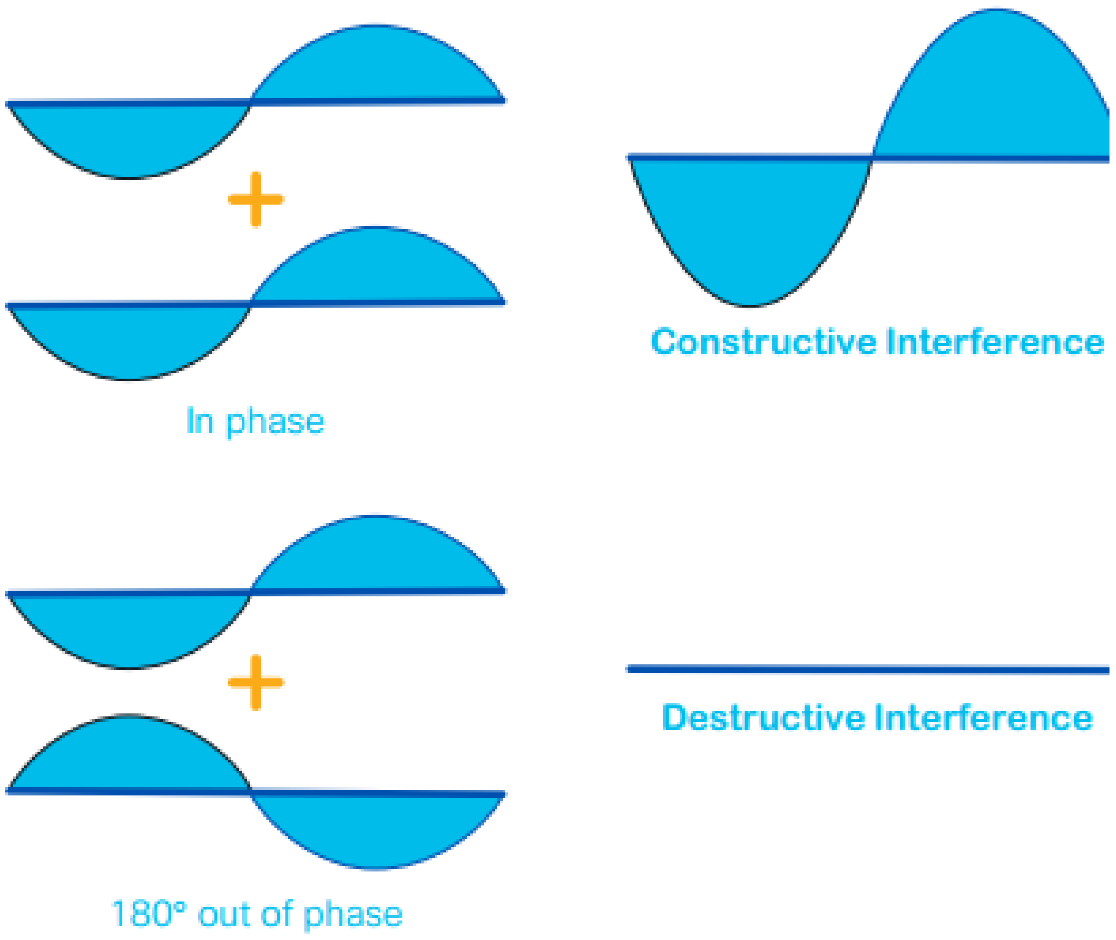
Interference Manipulation

- Another benefit that can be realized by quantum computing comes from manipulating interference
- Interference may be
  - constructive or
  - destructive
- Programmers of quantum algorithms (like Grover's and Shor's algorithms) endeavor to arrange qubits so that :
  - ***correct*** answers generate ***constructive interference***
  - ***incorrect*** answers generate ***destructive interference***
- Remember: Probability = Amplitude^2

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

Sums of the squares of probabilities must equal 1

$$\alpha^2 + \beta^2 = 1$$

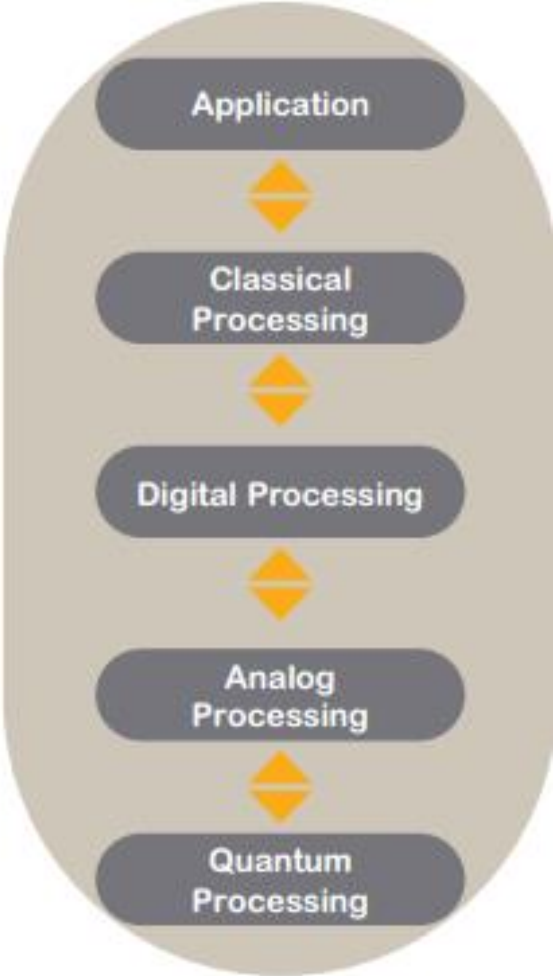


What Do Quantum Computers Look Like?

External (IBM)

External (IBM)

Internal (IBM)



Functions


QUESTIONS
ANSWERS