TEAM ABRAXAS

QUANTUM
IS HERE

THE TIME
IS NOW

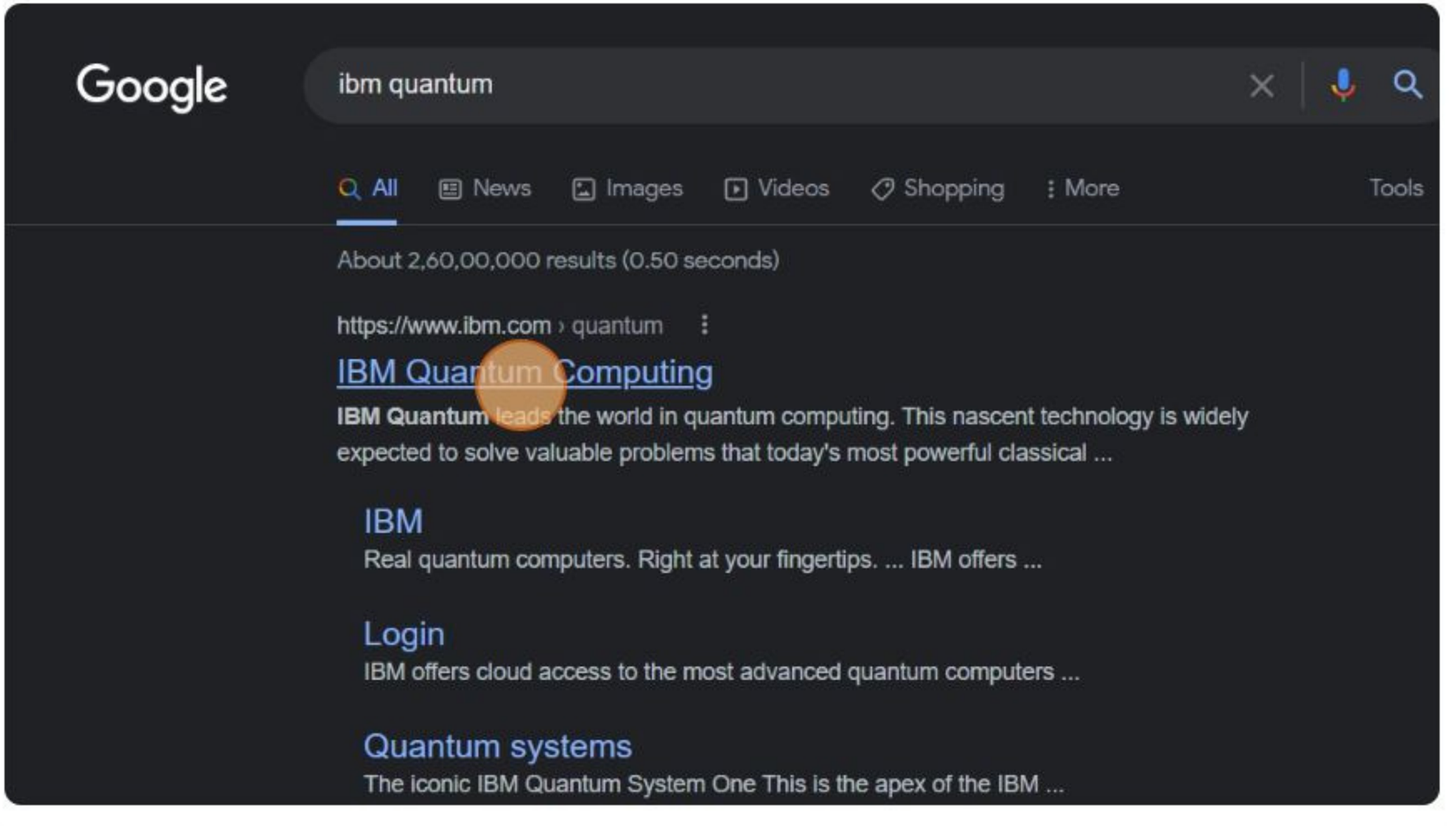
INTRODUCTION TO QUANTUM COMPUTING

Environment Setup

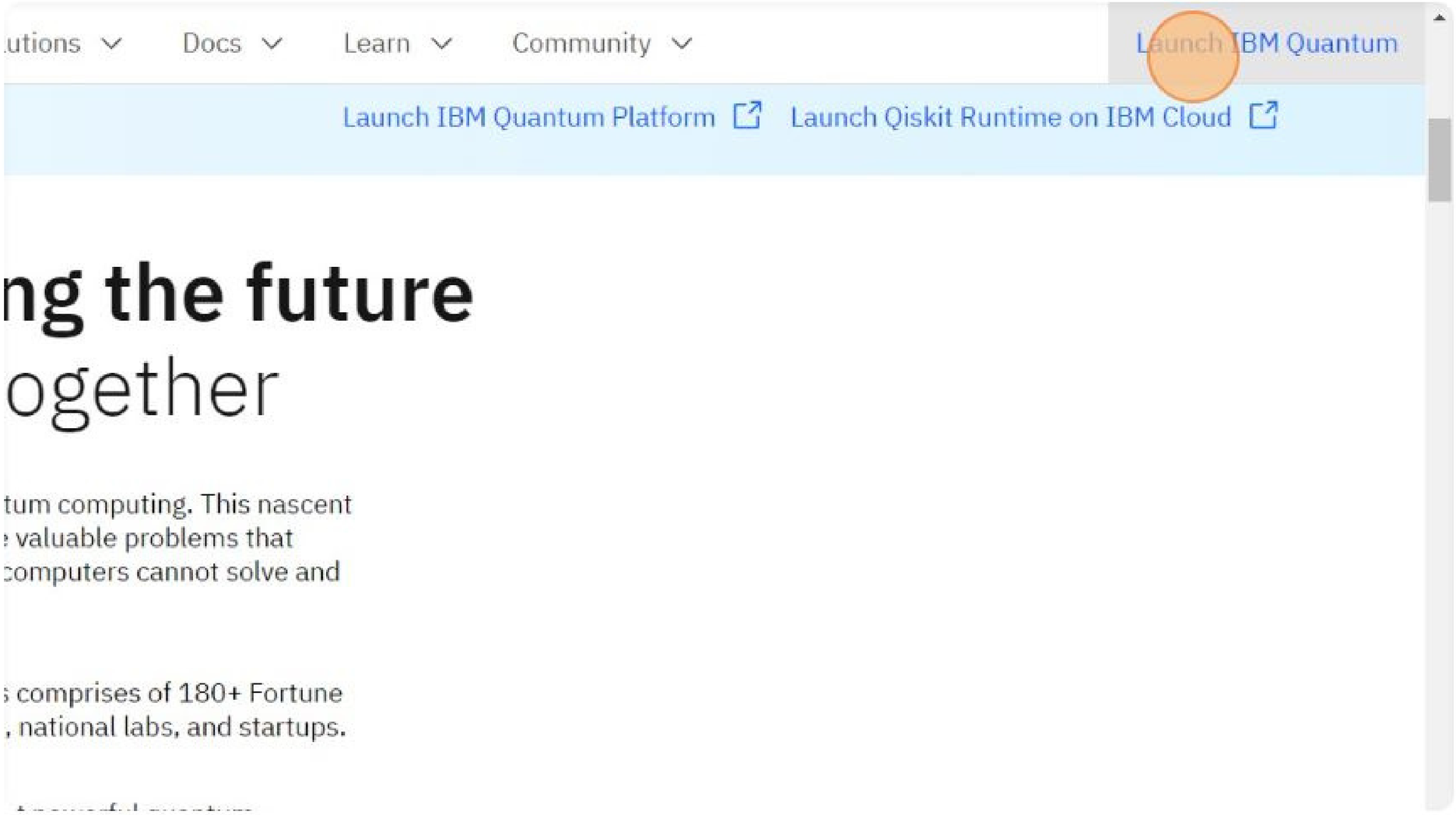
Visit this link for 'How To Setup IBM Quantum':
https://scribehow.com/shared/IBM_Quantum_Computing__Qvje0Ld1TiCRan1asfK-pQ

1 Search for IBM Quantum

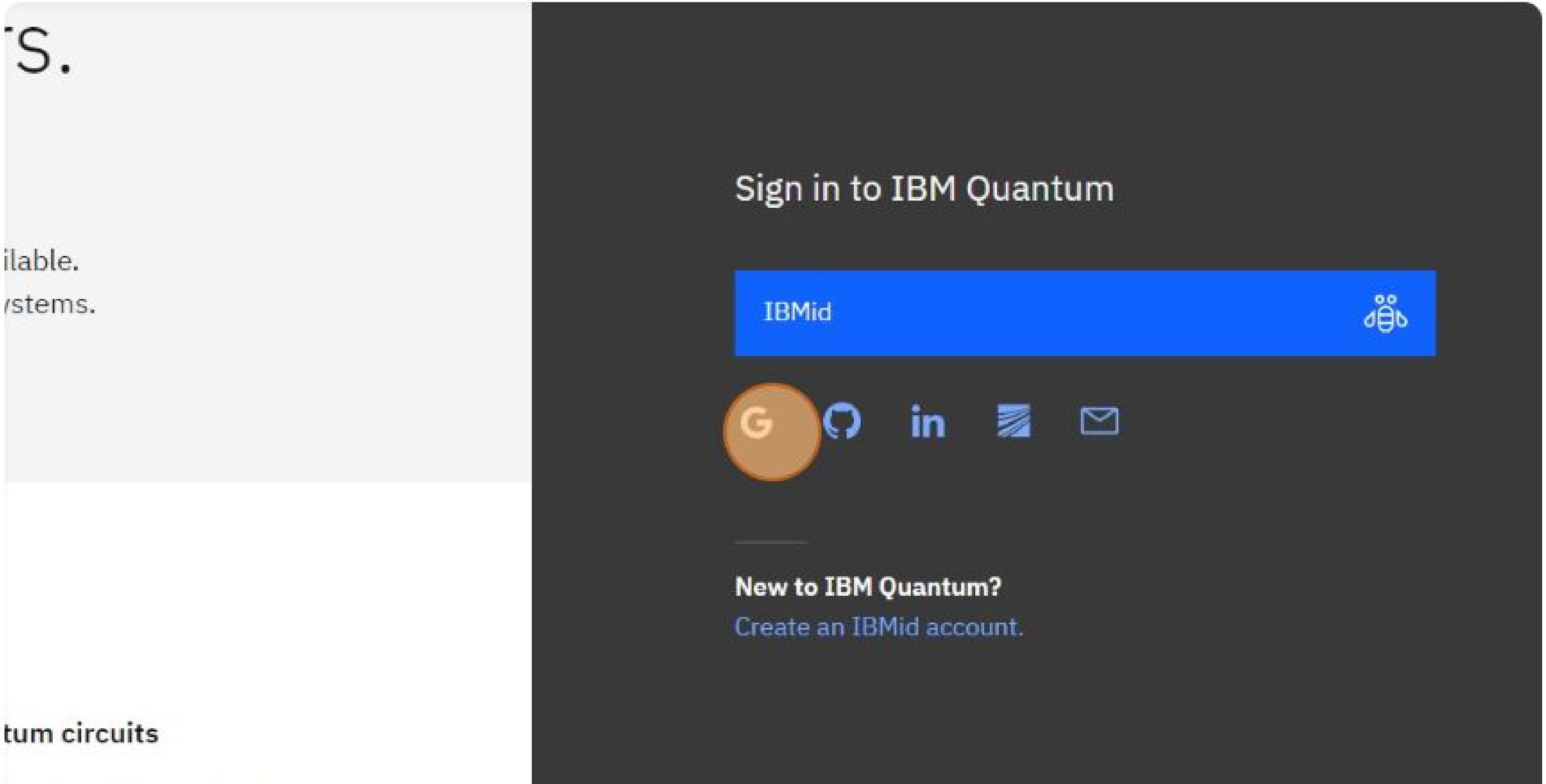
2 Click "IBM Quantum Computing"



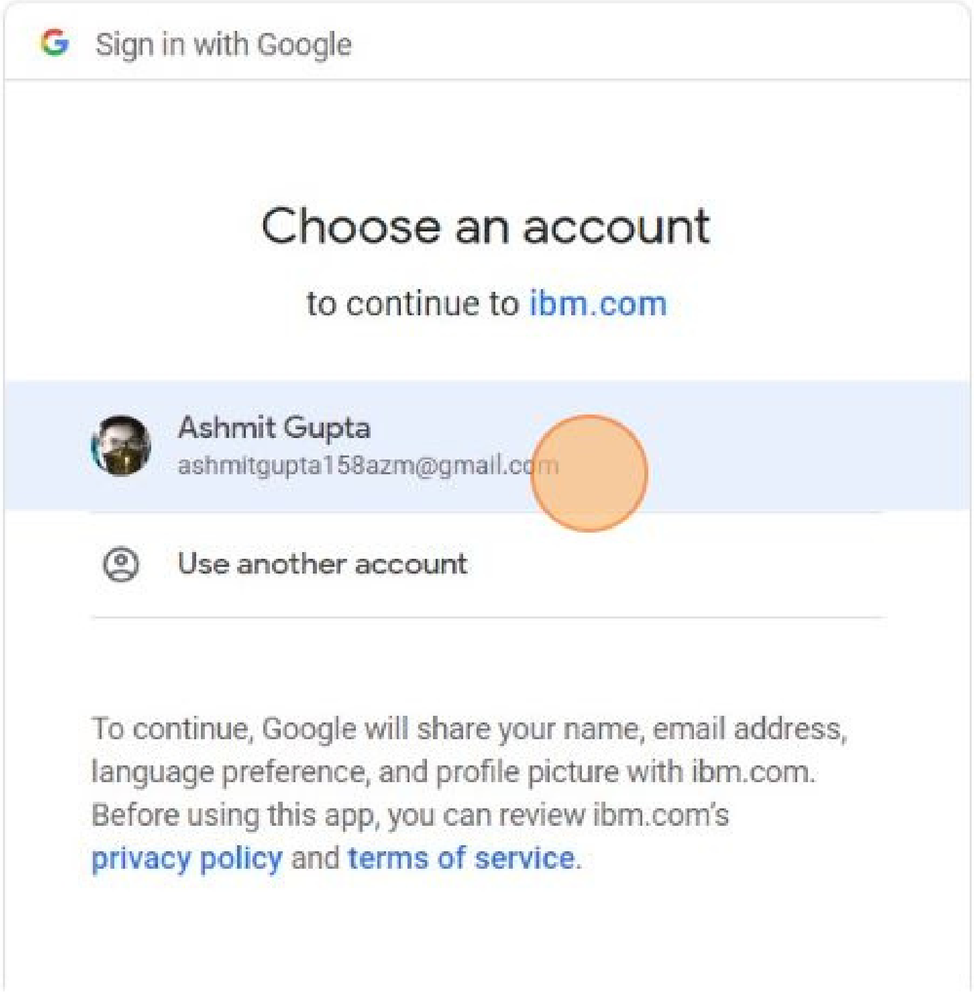
3 Click "Launch IBM Quantum"



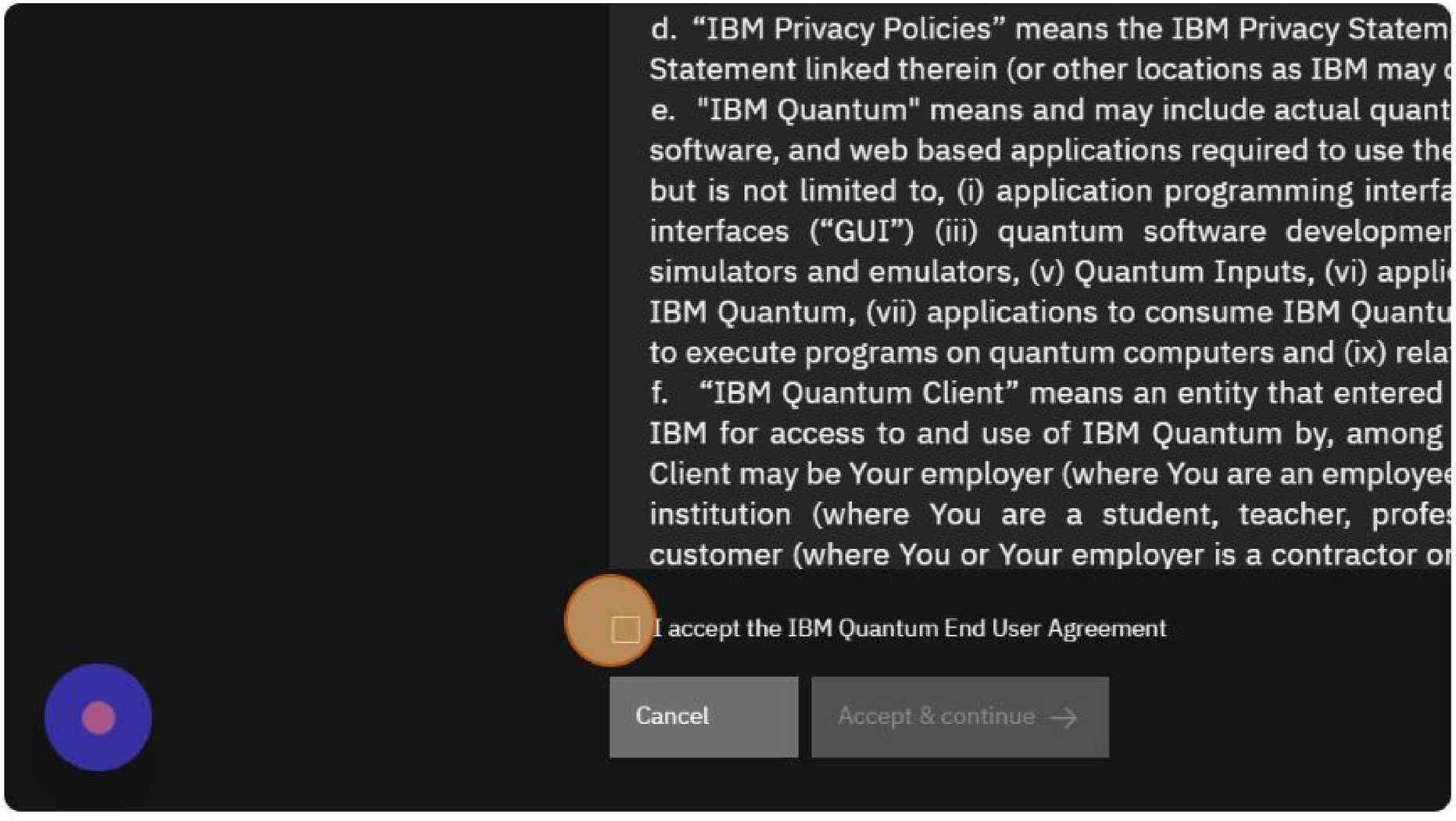
4 Click this icon.



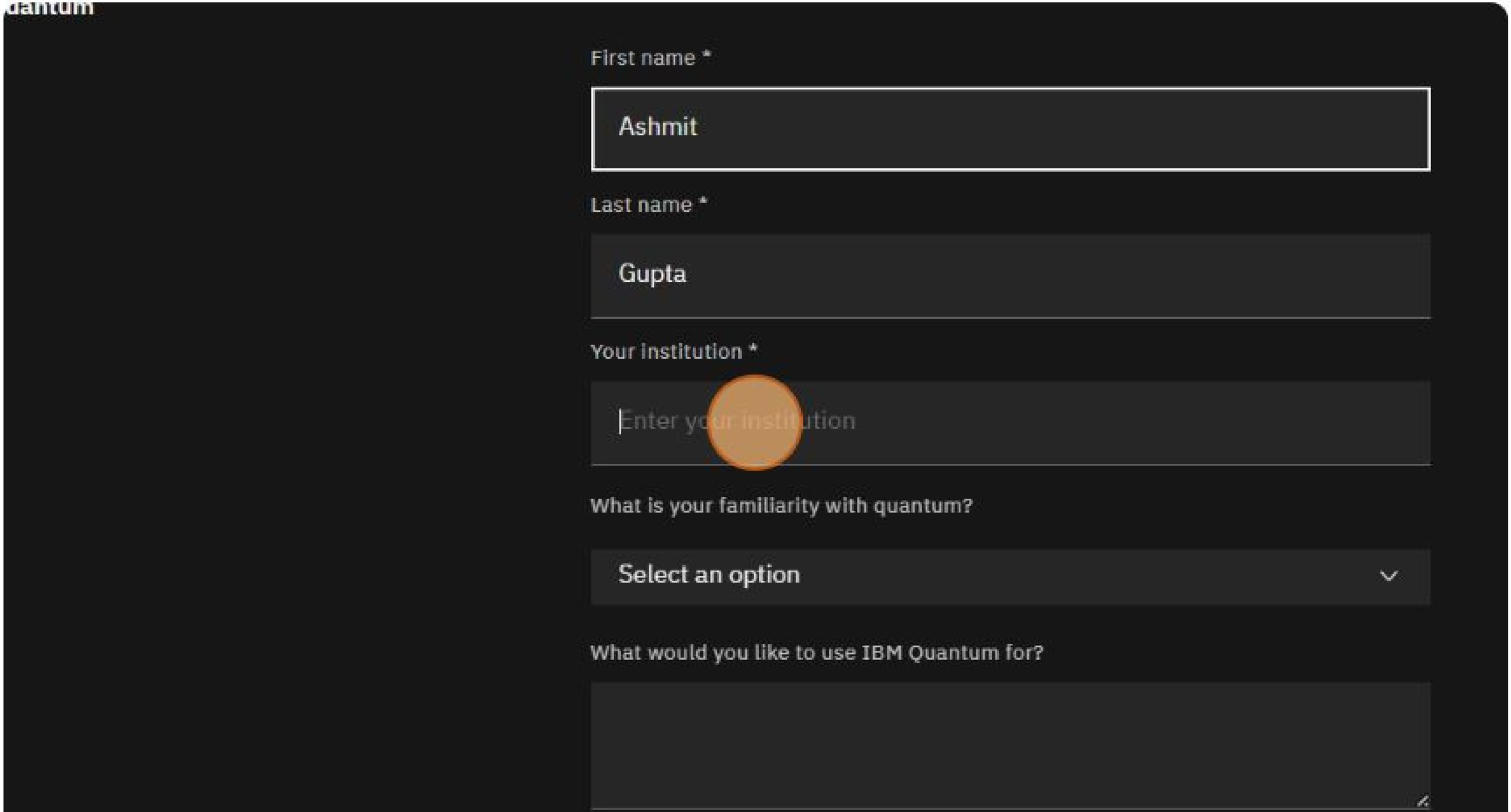
5 Select your Gmail account



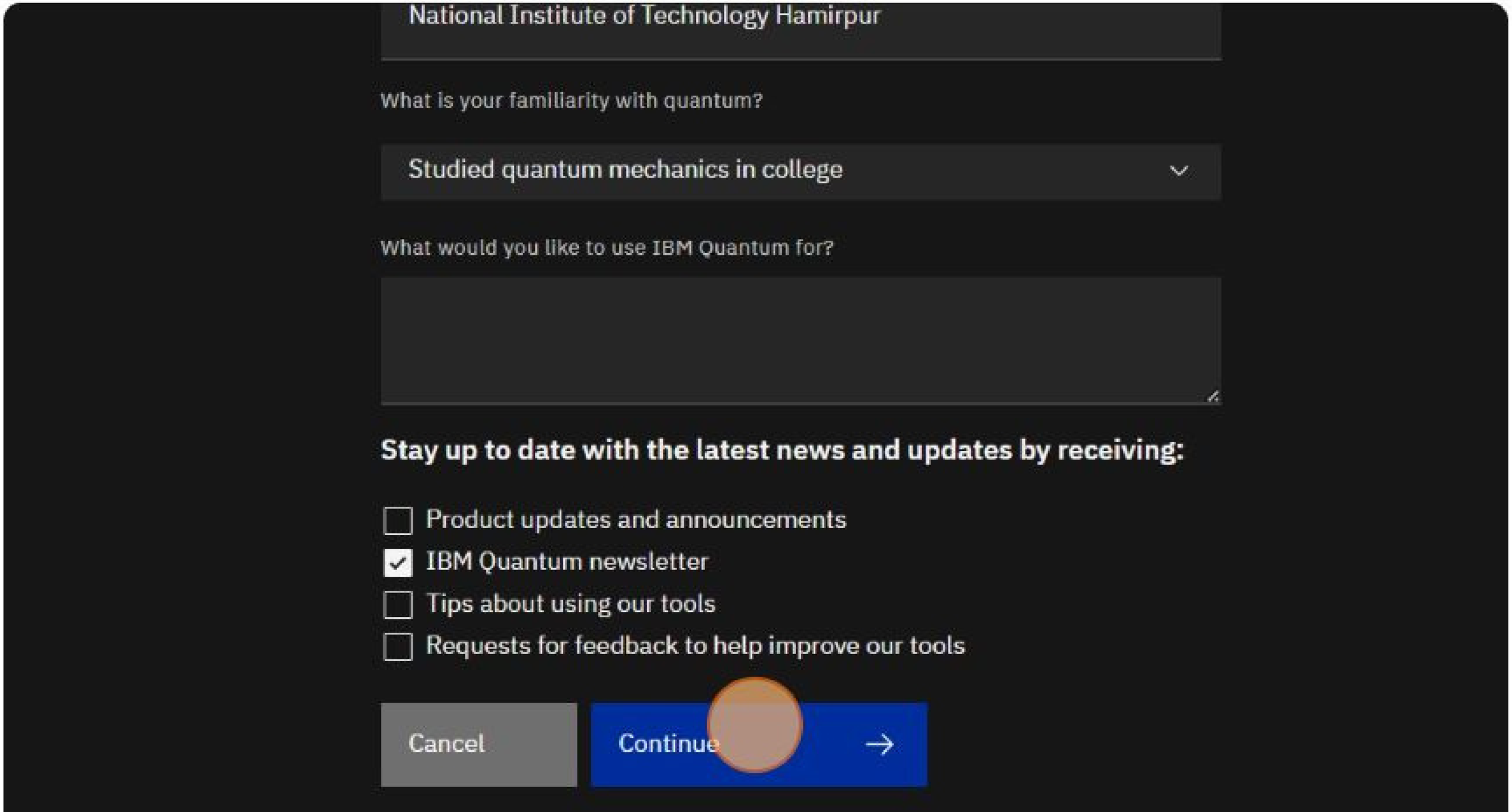
6 Read and accept the IBM Quantum End User Agreement



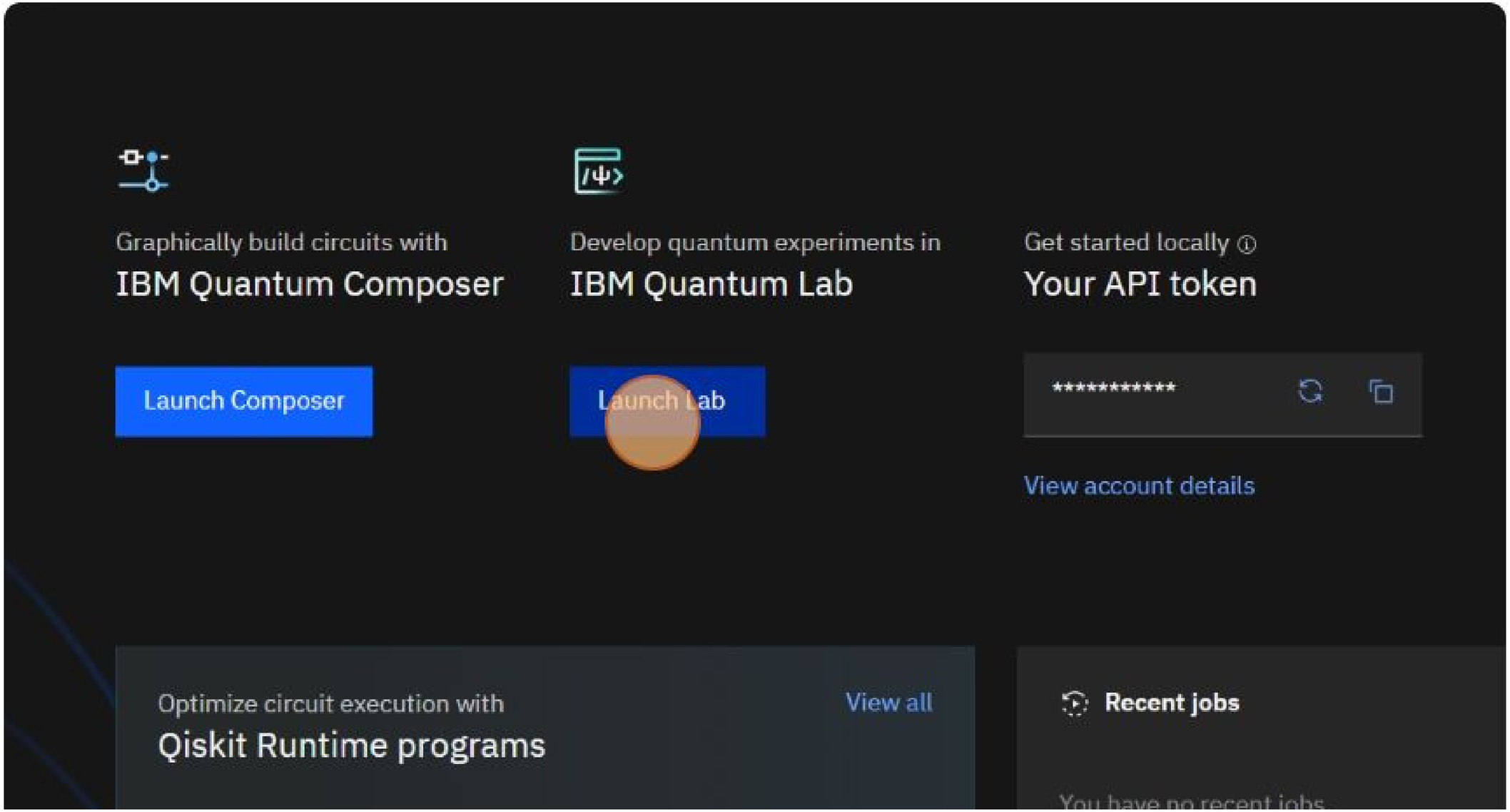
7 Fill in your details



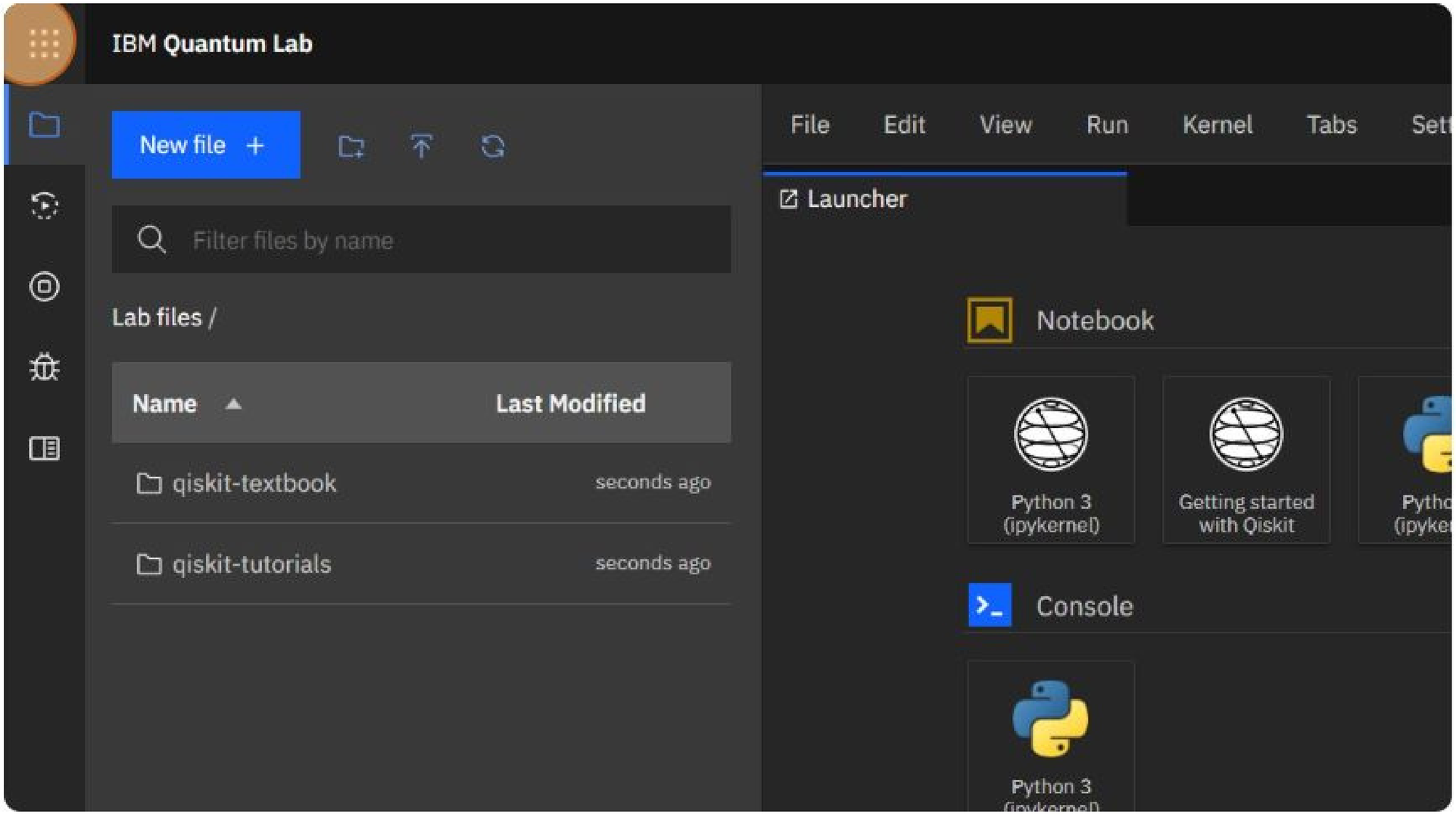
8 Click "Continue"



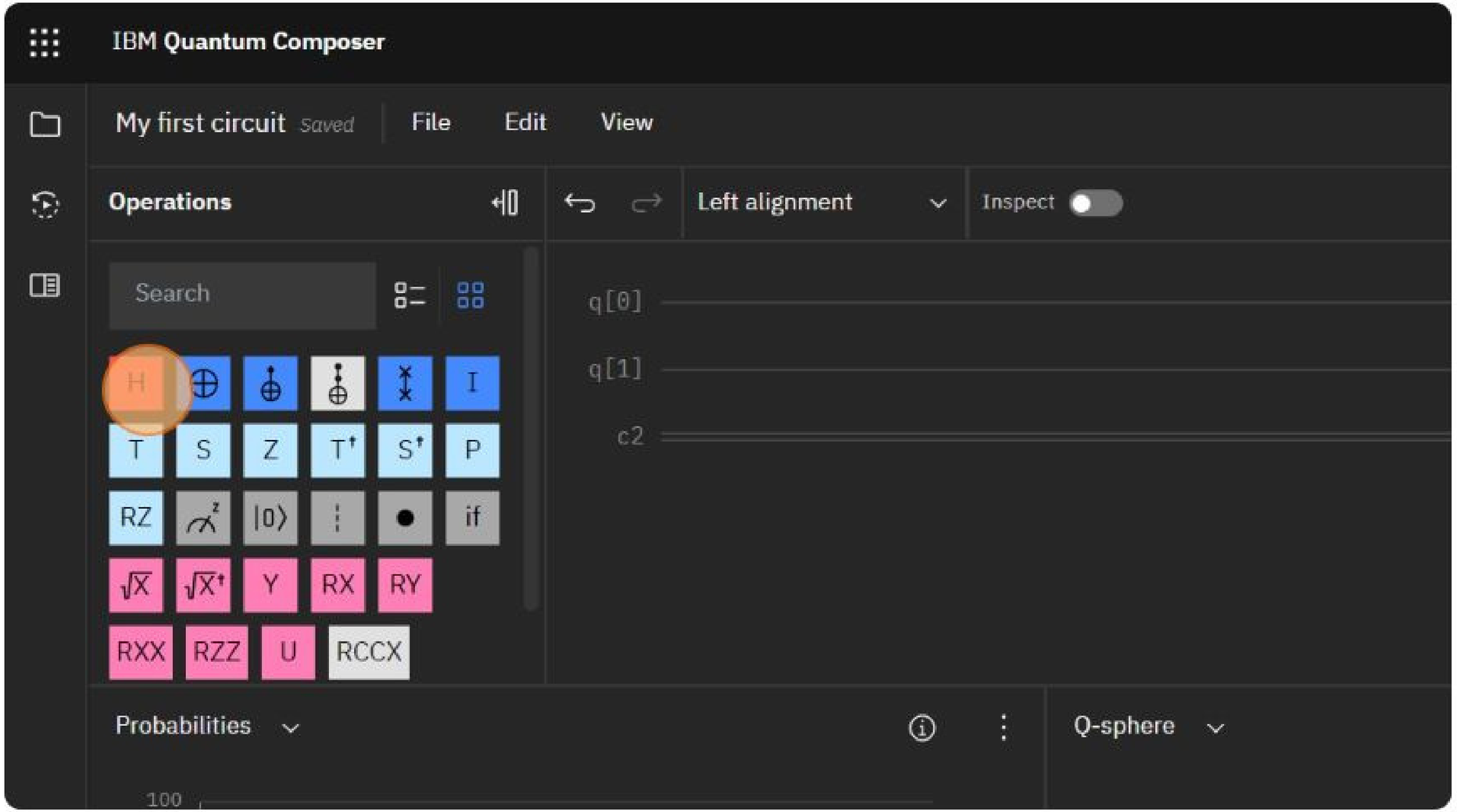
9 You can Launch Lab or Composer from here!



10 This is how IBM Quantum Lab looks like!



11 This is how IBM Quantum Composer looks like!



WHY QUANTUM COMPUTING

Why Quantum Computing ?

1: Quantum may make the ‘impossible’ possible.

Problems that are intractable even on today’s supercomputers? Problems that currently seem, well, impossible? We believe we may be able to solve some of them on future quantum computers. There is a real possibility that future quantum computers will solve certain problems exponentially faster than classical computers.

2: You might become a highly sought after subject matter expert or industry leader.

Today’s quantum computers are big and noisy, and there are a number of obstacles to overcome before we have error-corrected processors capable of tackling large problems.
You have an opportunity to develop useful algorithms that we can implement on today’s noisy quantum processors or near-term hardware, and then evolve these use cases alongside the hardware itself.

3: The world is already preparing for quantum's impact on data privacy.

A lot of research is going into both staying ahead of quantum decryption as well as developing quantum cryptographic protocols that utilize quantum computing principles to secure information.

4: You can program a real quantum computer — in minutes!

Qiskit is an open source python framework that hundreds of thousands of users around the world use to run billions of quantum circuits in a typical day. By learning Qiskit, you'll be able to program quantum hardware from IBM, AQT, IonQ, and more, explore how these hardware architectures differ, and implement quantum algorithms on real hardware.

5: You don't have to stick to R&D to be part of the quantum community.

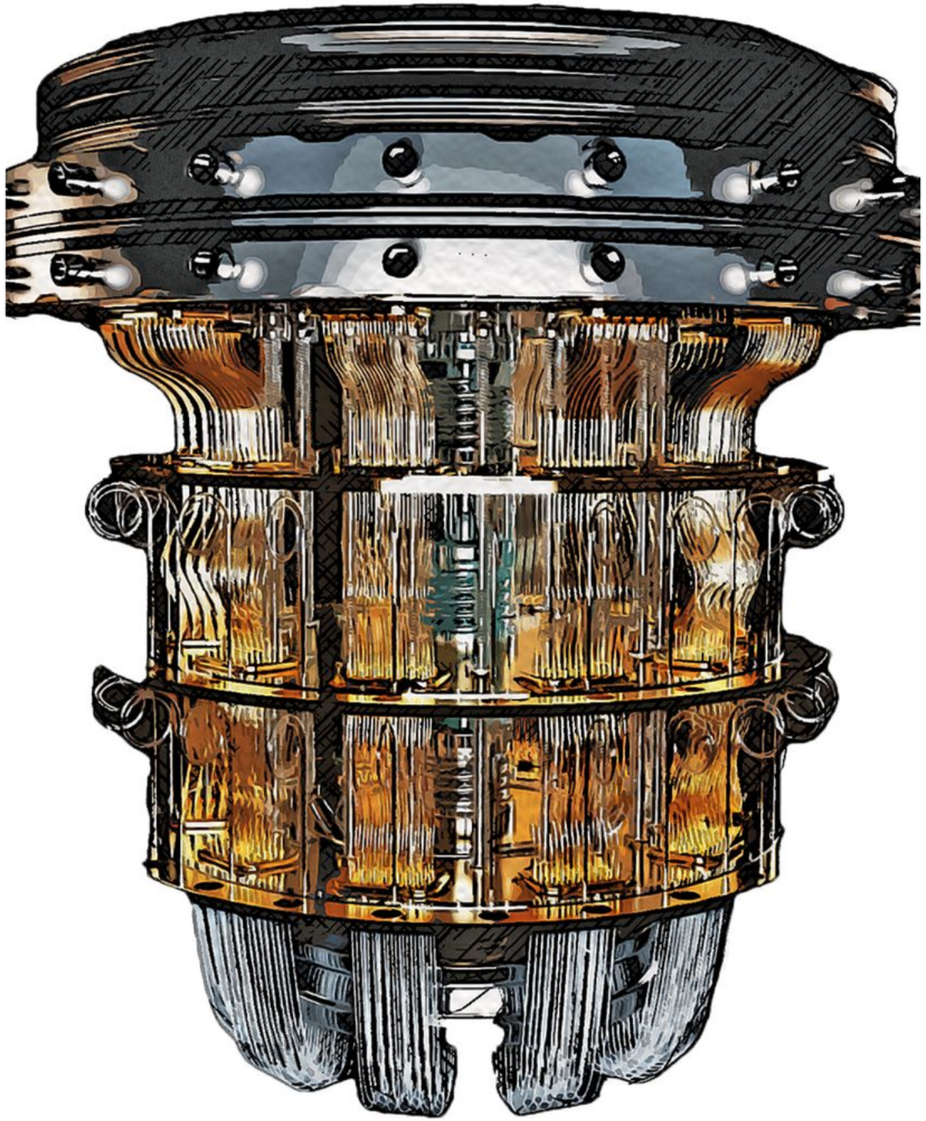
you don't even need a science background; there's an entire creative niche in quantum computing! I like to call it quantum creative. Quantum creative encompasses things like quantum games, quantum art, quantum music, and more. Basically, it involves creative projects that connect to quantum computing in some way.

Introduction to Quantum Computing

What Is Quantum Computing

Quantum computing is a multidisciplinary field comprising aspects of computer science, physics, and mathematics that utilizes quantum mechanics to solve complex problems faster than on classical computers. The field of quantum computing includes hardware research and application development.

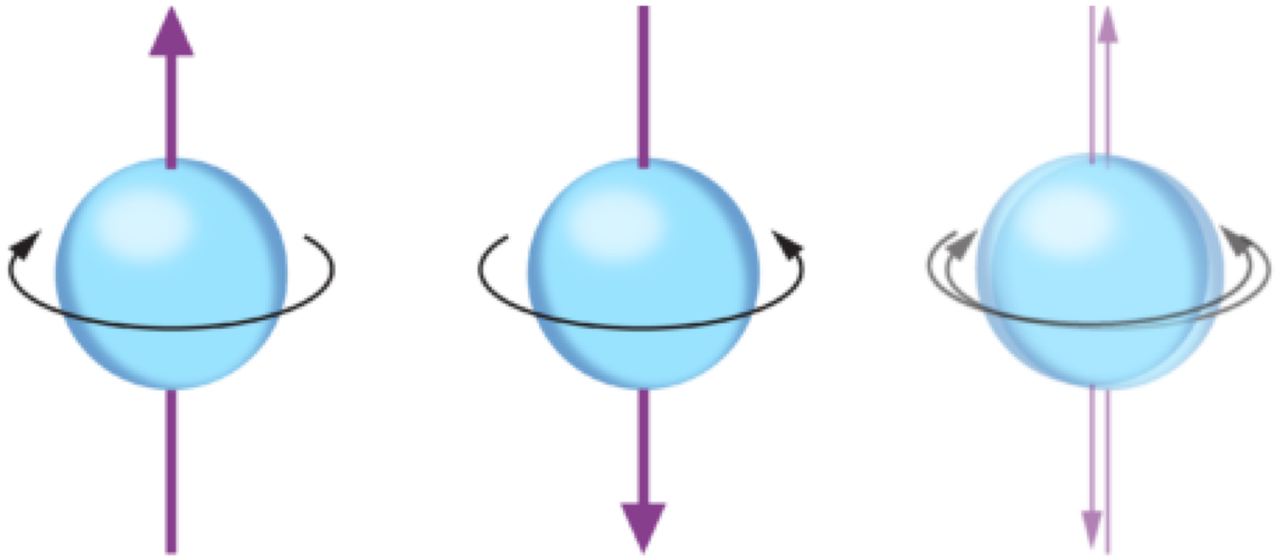
Quantum computers are able to solve certain types of problems faster than classical computers by taking advantage of quantum mechanical effects, such as superposition and quantum interference. Some applications where quantum computers can provide such a speed boost include machine learning (ML), optimization, and simulation of physical systems. Eventual use cases could be portfolio optimization in finance or the simulation of chemical systems, solving problems that are currently impossible for even the most powerful supercomputers on the market.



Superposition

One of the properties that sets a qubit apart from a classical bit is that it can be in superposition.

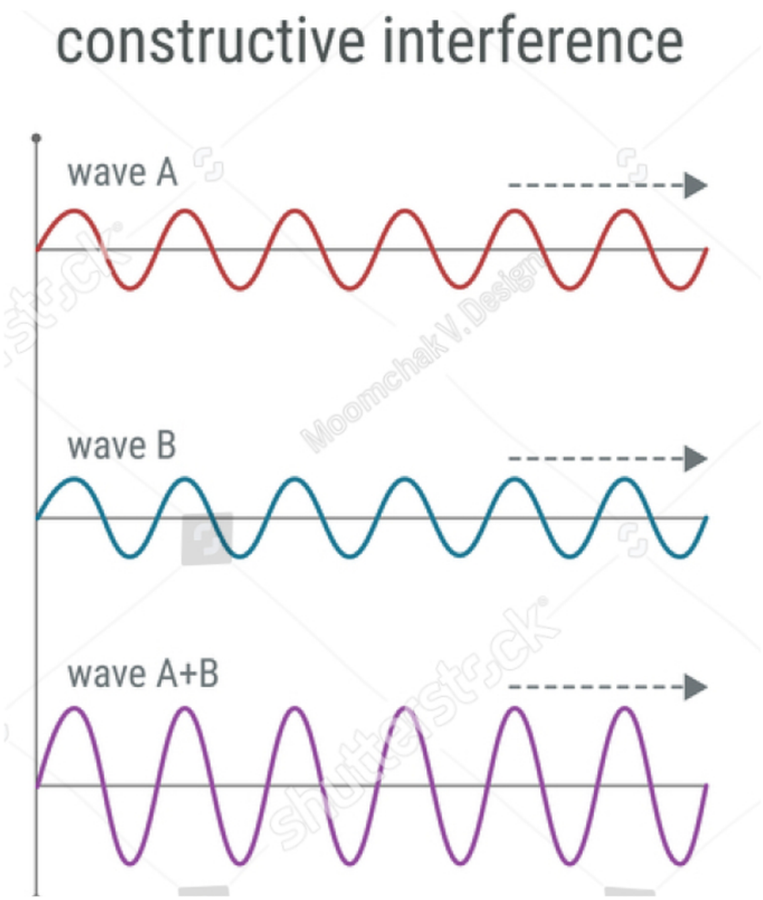
Qubits can be in a superposition of both the basis states |0> and |1>. When a qubit is measured (to be more precise: only observables can be measured), the qubit will collapse to one of its eigenstates and the measured value will reflect that state. For example, when a qubit is in a superposition state of equal weights, a measurement will make it collapse to one of its two basis states |0> and |1> with an equal probability of 50%. |0> is the state that when measured, and therefore collapsed, will always give the result 0. Similarly, |1> will always convert to 1.



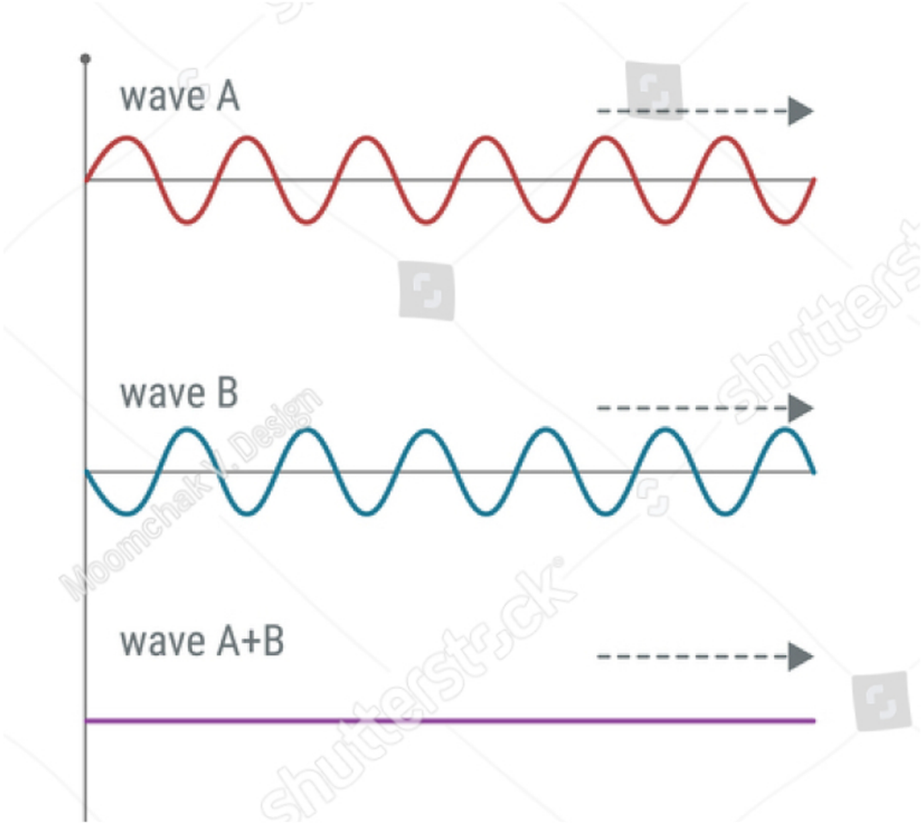
Interference

There are two kinds of quantum interference: constructive interference and destructive interference.

Two in-phase waves, which is to say they peak at the same time, constructively interfere, and the resulting wave peaks twice as high.



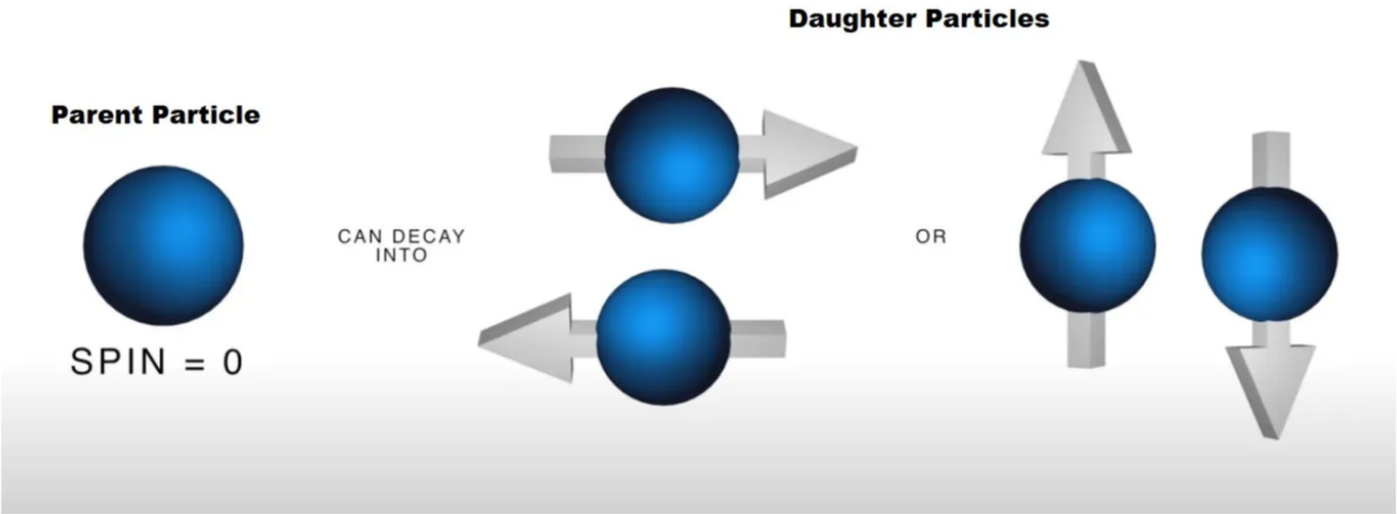
Two waves that are out-of-phase, on the other hand, peak at opposite times and destructively interfere; the resulting wave is completely flat.



All other phase differences will have results somewhere in between, with either a higher peak for constructive interference or a lower peak for destructive interference.

Entanglement

Quantum entanglement is the state where two systems are so strongly correlated that gaining information about one system will give immediate information about the other no matter how far apart these systems are.



In quantum computers, changing the state of an entangled qubit will change the state of the paired qubit immediately. Therefore, entanglement improves the processing speed of quantum computers. Doubling the number of qubits will not necessarily double the number of processes since processing one qubit will reveal information about multiple qubits (i.e. the entangled qubits).

Classical Computing vs Quantum Computing

Classical computing	Quantum computing
Used by large-scale, multipurpose computers and devices.	Used by high-speed, quantum mechanics-based computers.
Information is stored in bits.	Information is stored in quantum bits.
There is a discrete number of possible states: 0 or 1.	There is an infinite, continuous number of possible states.
Calculations are deterministic, meaning repeating the same input results in the same output.	Calculations are probabilistic, meaning there are multiple possible outputs to the same input.
Data processing is carried out by logic and in sequential order.	Data processing is carried out by quantum logic at parallel instances.
Operations are defined by Boolean algebra.	Operations are defined by linear algebra over Hilbert space.
Circuit behavior is defined by classical physics.	Circuit behavior is defined by quantum mechanics.

INTRODUCTION TO LINEAR ALGEBRA

Linear spaces and vectors

A linear space consists of a set of elements called points, and a set of elements called lines.

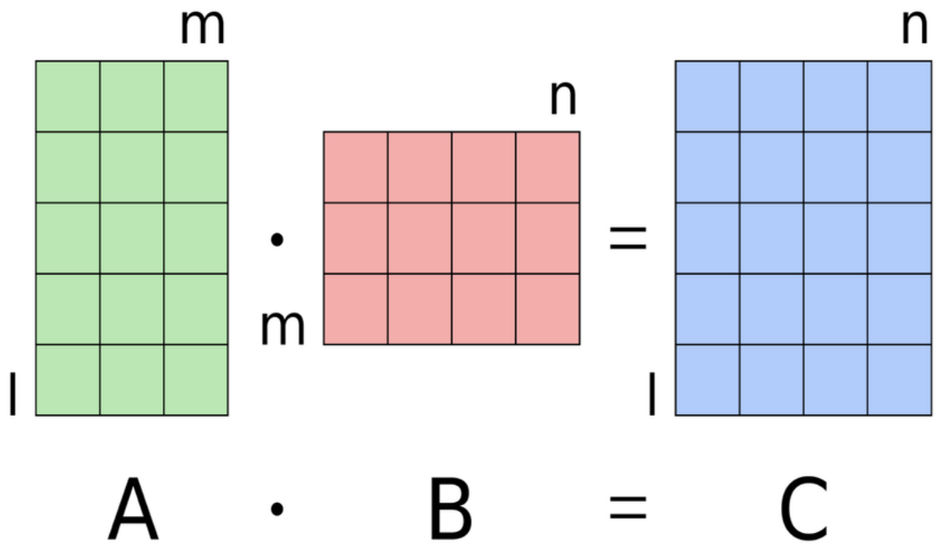
Each line is a distinct subset of the points. The points in a line are said to be incident with the line.

A vector is a geometric object with both length and direction, which is represented as an arrow whose starting point is arbitrary.

Matrix Multiplications

Matrix multiplication is a binary operation that produces a matrix from two matrices.

For matrix multiplication, the number of columns in the first matrix must be equal to the number of rows in the second matrix. The resulting matrix, known as the matrix product, has the number of rows of the first and the number of columns of the second matrix. The product of matrices A and B is denoted as AB.



Types of Matrix Multiplication

SCALAR MULTIPLICATION

single number is multiplied with every other element of the matrix

$$2 \cdot \begin{bmatrix} 10 & 6 \\ 4 & 3 \end{bmatrix} = \begin{bmatrix} 2 \cdot 10 & 2 \cdot 6 \\ 2 \cdot 4 & 2 \cdot 3 \end{bmatrix}$$

VECTOR MULTIPLICATION

entire matrix is multiplied by another one

Back to
Quantum Computing

Bits and Qubits

Instead of classical bits, quantum computers use quantum bits (or qubits for short).

Bit

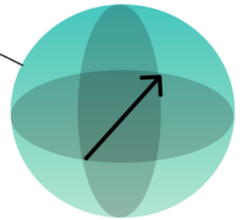
0

or

1

Qubit

$|0\rangle$



$|1\rangle$

Superposition

Linear combination between two or more states, e. g.

√0.8|0 > + √0.2 e^(i π/2)|1 >

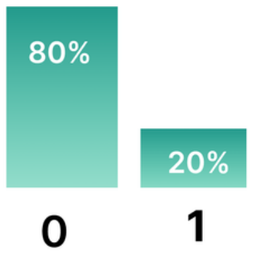
we call this a ket

0

1

Measurement

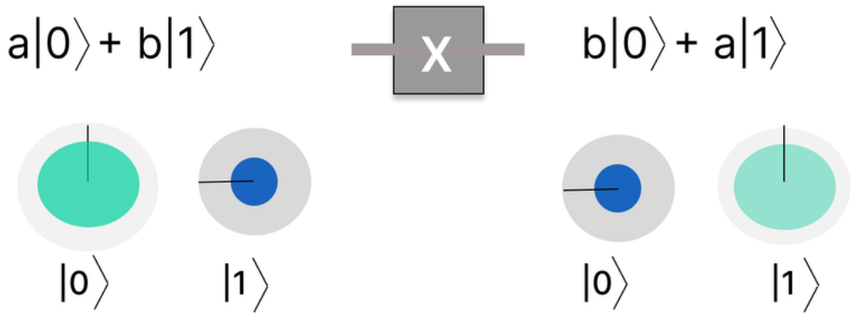
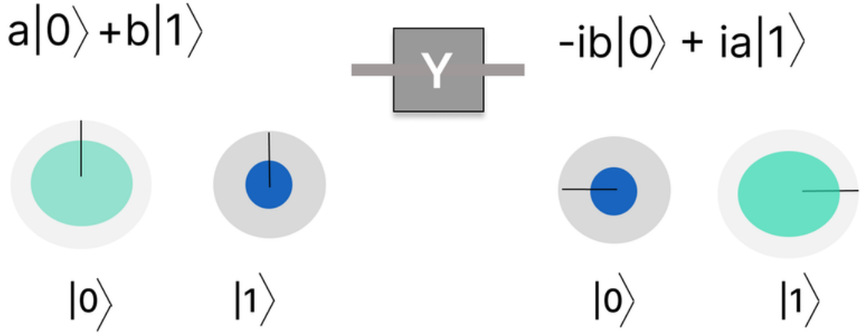
The full state is not accessible in one measurement, but multiple state preparations and measurements are needed to access the probability distribution.



Quantum states can also be described using **vectors**:

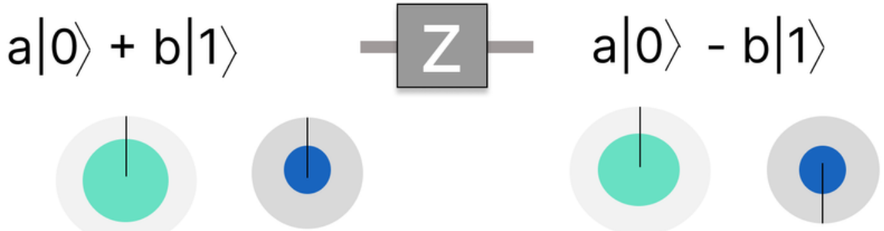
$$|0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \qquad |1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

One-Qubit Gates

Gate	Matrix	Ket and circle notation
Pauli-X is a 180° rotation around the x-axis; also known as the quantum NOT gate	$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$	
Pauli-Y is a 180° rotation around the y-axis	$\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$	

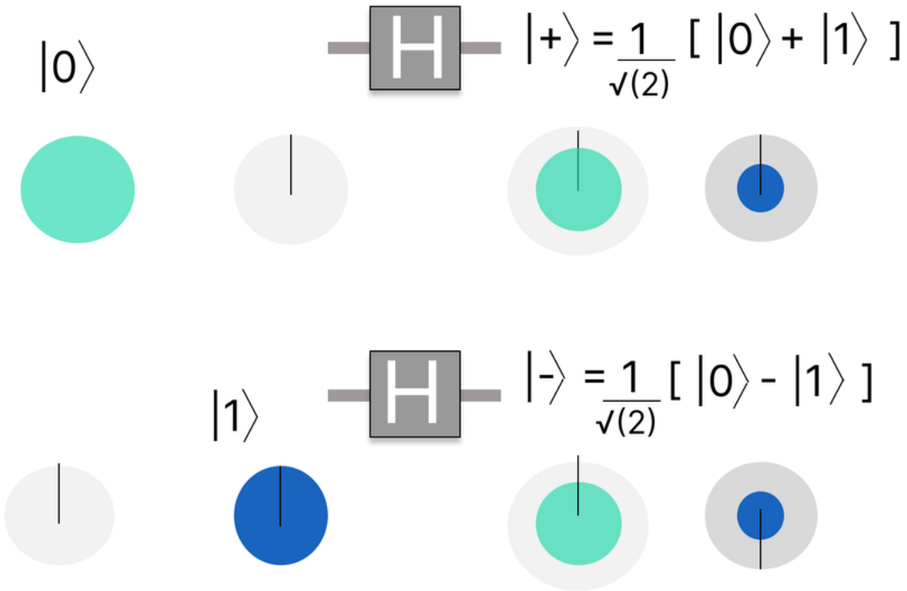
Pauli-Z is a 180° rotation around the z-axis

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



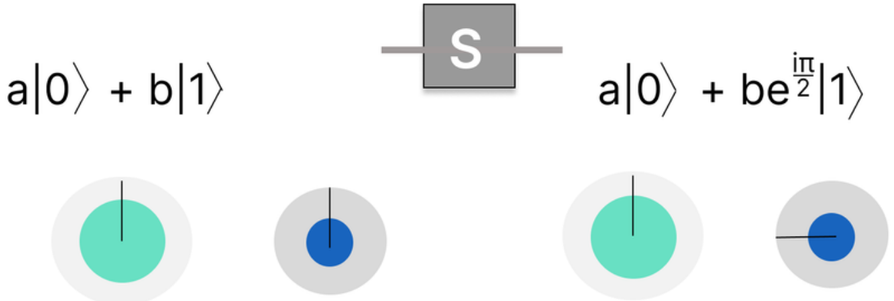
Hadamard maps to $|+\rangle$ and $|1\rangle$ to $|-\rangle$ used to create an equal superposition

$$\frac{1}{\sqrt{(2)}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$



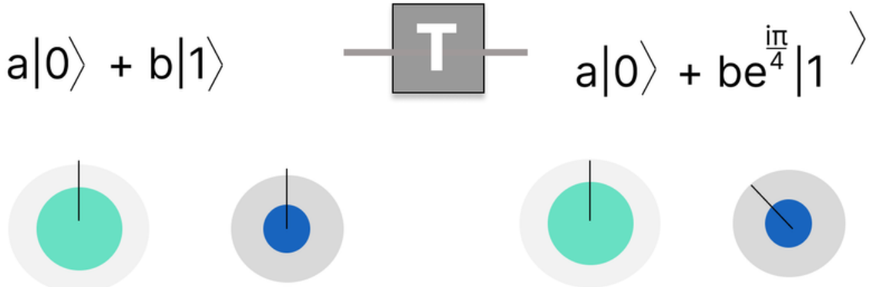
S is a 90° rotation around the z-axis; S S = Z; The inverse S+ rotates in the opposite direction

$$\begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}$$



T is a 45° rotation around the z-axis; T T = S ;The inverse T+ rotates in the opposite direction

$$\begin{bmatrix} 1 & 0 \\ 0 & e^{\frac{i\pi}{4}} \end{bmatrix}$$

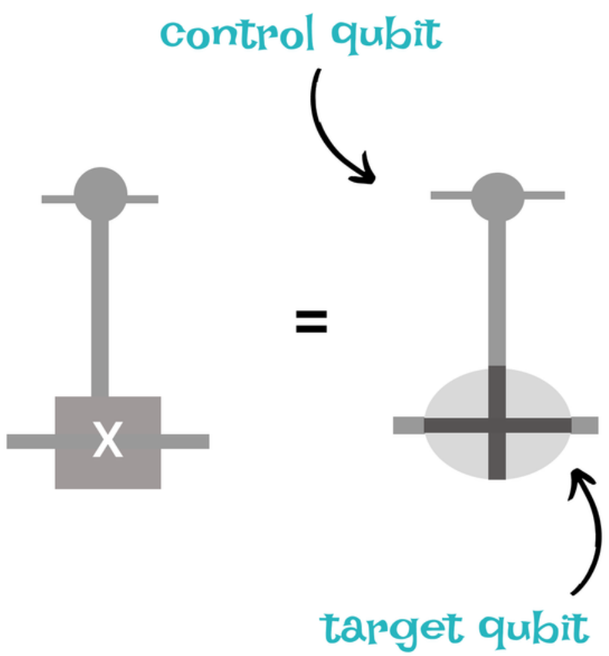


Quantum circuits are a model to visualize operations on qubits

Binary and decimal: You will find both the use of the binary representation of qubit states as well as the decimal representation.

Decimal	Binary	Decimal	Binary
|0>	|000>	|4>	|100>
|1>	|001>	|5>	|101>
|2>	|010>	|6>	|110>
|3>	|011>	|7>	|111>

Multi - Qubit Gates



Gate

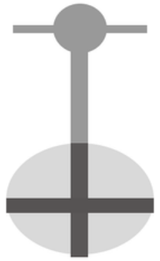
CNOT applies a Pauli-X gate to the target qubit if the state of the control qubit state is |1

Matrix

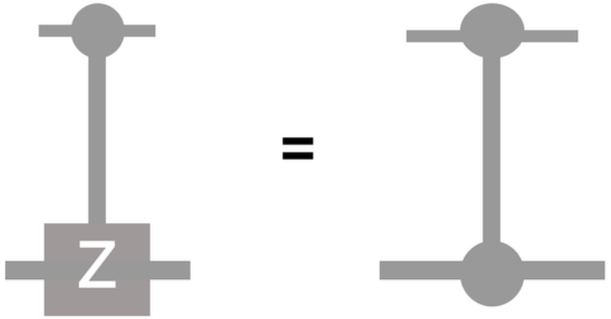
$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

Ket and circle notation

a|00> + b|01> + c|10> + d|11>



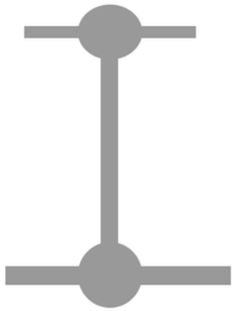
a|00> + b|01> + d|10> + c|11>



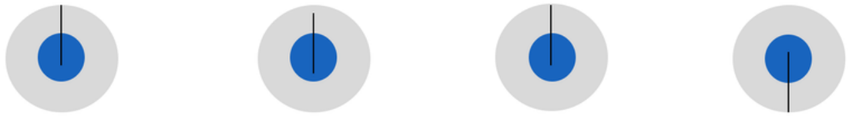
CZ applies a Pauli-Z gate to the target qubit if the state of the control qubit is |1

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

a|00> + b|01> + c|10> + d|11>



a|00> + b|01> + c|10> - d|11>

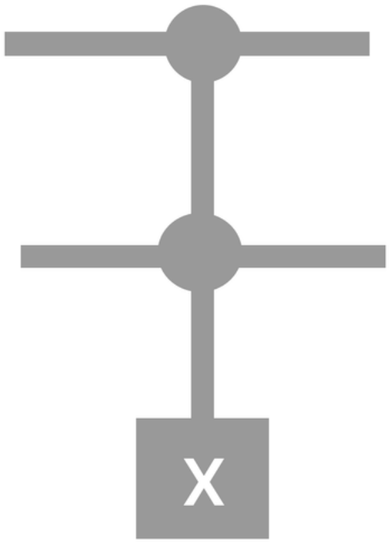


SWAP swaps the state of 2 qubits; can be implemented using 3 alternating CNOTs

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

a|00> + b|01> + c|10> + d|11>

a|00> + c|10> + b|01> + d|11>

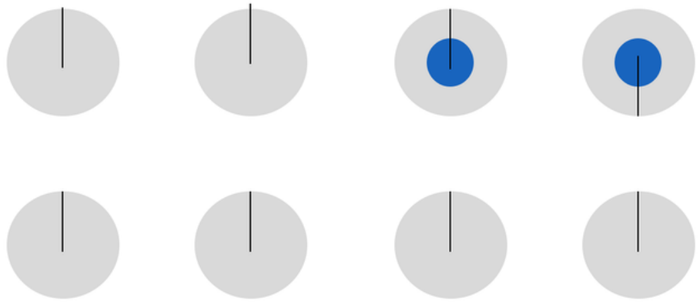


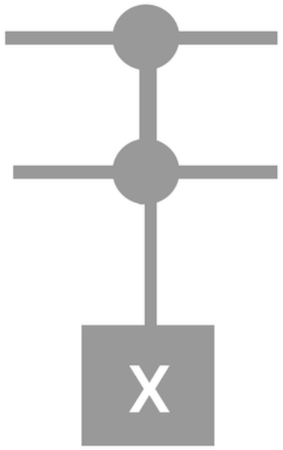
Toffoli applies a Pauli-X gate to the target qubit if both control qubits are in state ; can be used to construct a reversible version of the classical AND-gate
H

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

a|000> + b|001> + c|010> + d|011>

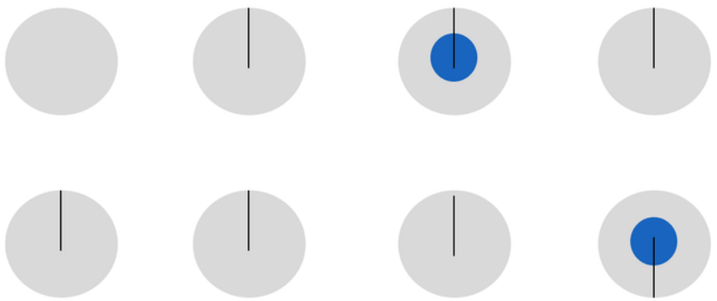
e|100> + f|101> + g|110> + h|111>





a|000> + b|001> + c|010> + h|111>

e|100> + f|101> + g|110> + d|011>



Introduction to Qiskit

Qiskit (Quantum Information Software Kit for Quantum Computation) is an open-source software development kit (SDK) for working with quantum computers at the level of circuits, pulses, and algorithms. It provides tools for creating and manipulating quantum programs and running them on prototype quantum devices on IBM Quantum Experience or on simulators on a local computer.

1) **Creating Quantum Circuit**

```
qr = QuantumRegister(3 , 'q')
cr = ClassicalRegister(3, 'c')
qc = QuanturnCircuit(qr, anc, cr)
```

OR:

```
qc = QuantumCircuit(4, 3)
```

(2) 1-qubit gates: (All rotation follow right hand rule)

qc.x([0,1]) or ,y(), z()
Rotate π by x, y,z axis

qc.rx(θ) qc.ry(θ), qc.rz(θ)
Rotate θ by axis.

p = rz = u1 are equivalent
s = rz(π /2), t = rz(π /4)

h Rotate π by axis (x + z)/√2

(**3) Control gates:**
qc.cz(ctrl, target). Or any other c-gates

qc.cx(0,1) = qc.cnot(0,1)
= qc.append(cx1, [0,1])
where cx1 = XGate .control

ccx0, 1, 2) = mct ([0,1], 2)

qc.to_gate() make qc to gate

swap = cx0, 1) + cx1,0) + c(0,1)

4.Other methods or qc:

qc.initialize([1/√2, 0,0,1/√2] , [0,1]

qc.barrier() or qc.barrier([0,1])

qc.draw()

(5) Measurement:

qc.measure ([0,1,2], [0,1,2]) or qc.measure(qr, cr)

qc. measure_all) create new cr to store all result.

QUANTUM COIN GAME

Quantum Coin Game

What is Quantum Coin Game ?

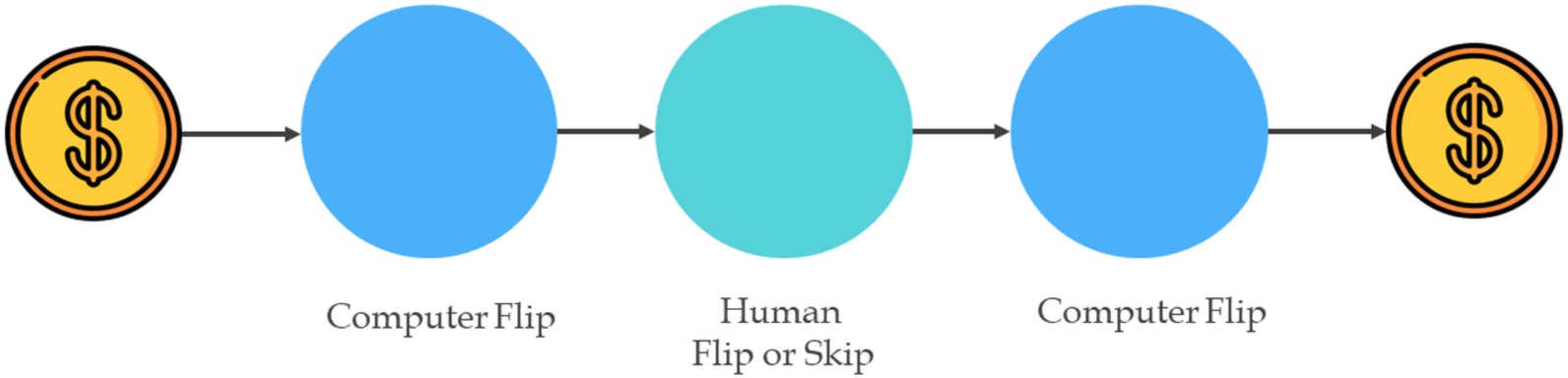
Quantum Coin Game is one of the fundamental concept of quantum computing, which uses simple implementation of quantum gates or more precisely uses the wierdness of quantum mechanics, to win about 97% of the time, when played against an opponent. Flipping of coin and say heads or tails.

Where the concept came from ?

The concept of Quantum Coin Game came from the idea of classical coin game which can only show heads and tails. But since the game utilizes the concepts of quantum mechanics, it would be interesting to see what could be the outcome of the whole experiment.

What is the main idea of this game ?

The main concept of this game is how the quantum computer uses the power of quantum superposition, which tells an object can exists in 2 different states at the same time, to win absolutely everytime.



What are the rules of this game ?

1. Quantum Computer plays a move but it is not revealed to the Opponent(Human).
2. Opponent(Human) plays a move and it is also not revealed to the Quantum Computer.
3. Finally Quantum Computer plays a move.
4. Results are shown. If its heads, then Quantum Computer wins. Else, Opponent(Human) wins.

NOTE: "Playing a move" refers to "Flipping the coin" and we consider the coin as fair coin.

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Applications of Quantum Computer

1. Research in High Energy Physics

One of the top applications of quantum computing is its utility in research in the field of particle physics or high energy physics. Particle physics models are highly complex. Hence, require lengthy computing time and a vast number of resources for numerical simulations.

2. Training Artificial Intelligence

Quantum computing applications include the crucial task of training artificial intelligence. The intelligence demonstrated by machines requires training; quantum computing can simplify the task of analyzing millions or even billions of data points with accuracy and speed.

3. Financial Modeling

One of the top applications of quantum computing includes its use in financial modeling. Based on expected returns and associated risks, finding the right mix for profitable investments is significant for financial investors to survive in the market. This process involves the analysis of thousands of factors that have the potential to affect stock prices.

4. Cybersecurity

Enhancement of cybersecurity is one of the most crucial applications of quantum computing. Quantum computers can crack encryption algorithms that protect the infrastructure and sensitive data of the internet. Estimates predict that a quantum computer with 20 million qubits is capable of breaking such encryptions in less than 8 hours.

5. Discovery of New Materials

Applications of quantum computing include the discovery of new materials. Quantum computing is based on quantum-mechanical phenomena; hence, it can represent other quantum systems more efficiently than conventional computers. For instance, consider Schrödinger's equation. A quantum machine can solve Schrödinger's equation for a molecule to accurately calculate its allowed energy states. Quantum computers can also simulate complex molecules that conventional computers are unable to.

Conclusion

Overall, quantum computing is taking giant leaps in shaping several domains of everyday life, ranging from traffic optimization to cybersecurity. According to GlobeNewswire, the global market for quantum computing was valued at US $507.1 Mn in 2019, and it is expected to reach US $4531.04 Bn by 2030.

Careers in Quantum Computing and Engineering

1. Quantum Computing Measurement Engineer

2. Quantum Device Engineer

3. Quantum Research Scientist

4. R&D FLARE Research Associate in QC and Quantum Communication

5. Quantum Software engineer

Upcoming Opportunities for Beginners

There are certain upcoming opportunities for beginners in the field of Quantum Computing:

1) QHack 2023
2) Qiskit Summer School 2023
3) Womanium Quantum 2023
4) Workshop of QBronze, QSilver by QIndia
5) Quantum Open Source Foundation
6) Contribution to Open Source Quantum Computing Libraries (Qiskit, Pennylane, etc)