

01-07-2025

QUANTUM COMPUTING

“Unlocking the Future
of Technology”



B.Tech
CSE-Data Science

“Beyond Binary – Into the Quantum Era”

Department Vision

To become a leading center of excellence in Computer Science and Engineering (Data Science), empowering students with advanced knowledge, ethical values, and innovative skills to address real-world challenges and contribute meaningfully to the global data-driven society.

Department mission

- To nurture future-ready professionals in Data Science by integrating theoretical knowledge with industry practices through advanced infrastructure, cutting-edge technologies, and experiential learning.
- To instill ethical values, integrity, and social responsibility in students, enabling them to make meaningful contributions to society through ethical decision-making.
- To foster creativity, innovation, and interdisciplinary research, empowering students to transform data into actionable insights and address real-world challenges.



Program Educational Objectives

PEO 1: To prepare our students to find suitable employment commensurate with their qualification.

PEO 2: To create good entrepreneurs who may contribute to the nation building and generate job opportunities for others.

PEO 3: To develop proficiency in students for higher studies and R & D for the solution of complex problems for betterment of the society.

PEO 4: To develop students as responsible citizens with high moral and ethical values who can become asset to a vibrant nation.

Program Specific Outcomes

PSO 1: Apply computational, statistical, and machine learning techniques to analyze and interpret complex data, developing innovative solutions for real-world challenges in diverse domains.

PSO 2: Design and implement data-driven systems with ethical considerations, ensuring transparency, fairness, and social responsibility in decision-making processes.

PSO 3: Engage in interdisciplinary research, lifelong learning, and innovative practices to contribute to advancements in Data Science and emerging technologies.



Program Outcomes

PO 1: Engineering Knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

PO 2: Problem Analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

PO 3: Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO 4: Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions

PO 5: Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

PO 6: The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO 7: Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO 8: Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice

PO 9: Individual and team work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

PO 10: Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

PO 11: Project management and finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO 12: Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.



Opening hook

“What if a computer could solve in minutes problems that would take today’s supercomputers thousands of years? Welcome to the fascinating world of Quantum Computing.”

Why This Topic Matters ?

Quantum computing is not just an upgrade to classical computing—it’s a complete reimagination of how we process information. From drug discovery to climate modeling, AI, and even space exploration, the potential is boundless.



This Magazine Covers

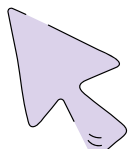
- The basics and history of quantum computing.
- How qubits, superposition, and entanglement transform computation.
- Applications of quantum computing in real-world industries.
- The global race to achieve quantum supremacy.

- The future possibilities, challenges, and

“Together, let’s step into the quantum era and explore the future of computing.”

“Quantum Computing Magazine”

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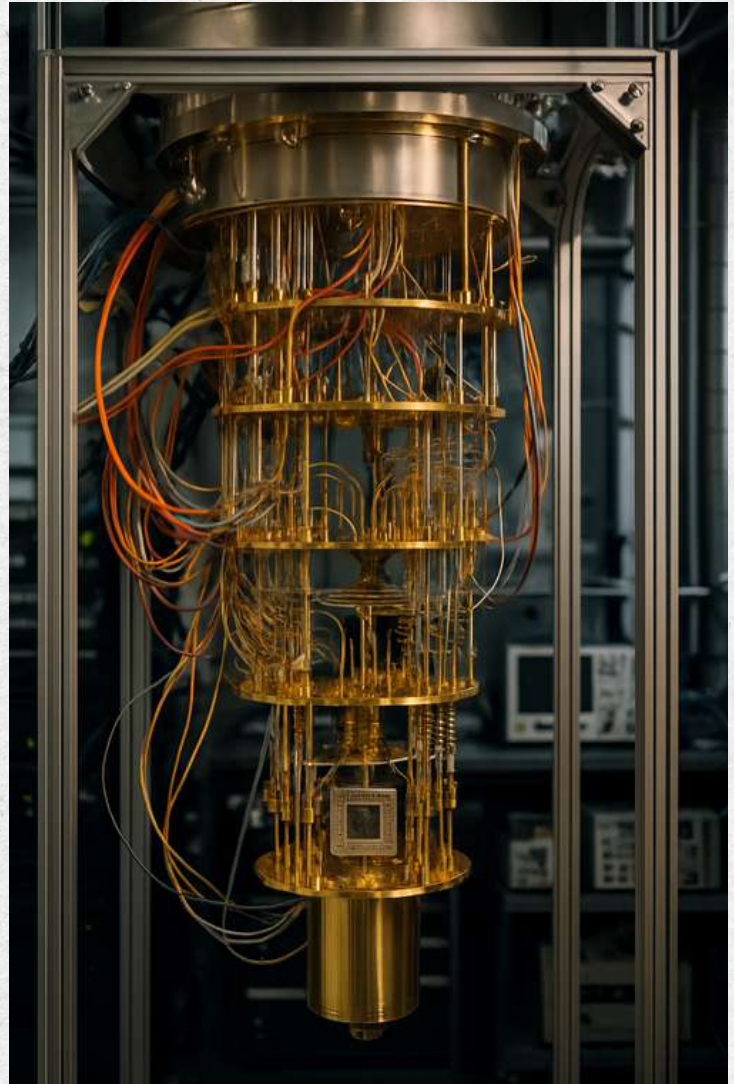
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1.Introduction to Quantum Computing

1.1 What is Quantum Computing ?

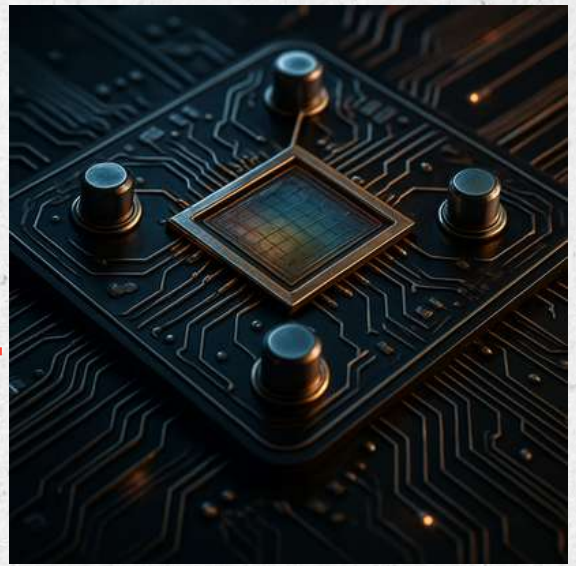
Quantum computing is an advanced form of computing that harnesses the unique principles of quantum mechanics to process information. Unlike traditional computers, which rely on bits (represented as 0 or 1), quantum computers use qubits. A qubit can exist as a 0, a 1, or even both at the same time through a phenomenon known as superposition.



This fundamental difference gives quantum computers extraordinary power. While a classical computer explores solutions one by one, a quantum computer can evaluate multiple possibilities simultaneously, making it ideal for solving problems that are practically impossible for classical machines.

“In short, quantum computing is not just faster—it is fundamentally different, unlocking entirely new ways to process information.”

1.2 When & Who Discovered Quantum Computing



○ 1980 – Yuri Manin

Suggested that quantum mechanical principles could model computations better than classical computers.

○ 1981 – Richard Feynman

Proposed that simulating physics efficiently would require quantum computers.

○ 1985 – David Deutsch

Introduced the concept of a Universal Quantum Computer, forming the mathematical foundation.

○ 1994 – Peter Shor

Developed Shor's Algorithm, showing quantum computers could break modern encryption—proving their potential power.

○ 2000s–Present

Tech giants like IBM, Google, and D-Wave began building real quantum processors.

2. Key Principles of Quantum Computing

(i). Qubits – The Building Blocks

Quantum computing is powered by qubits (quantum bits). Unlike a classical bit that can only be 0 or 1, a qubit can exist as:

- 0
- 1
- Or both 0 and 1 at the same time (through a phenomenon called superposition).



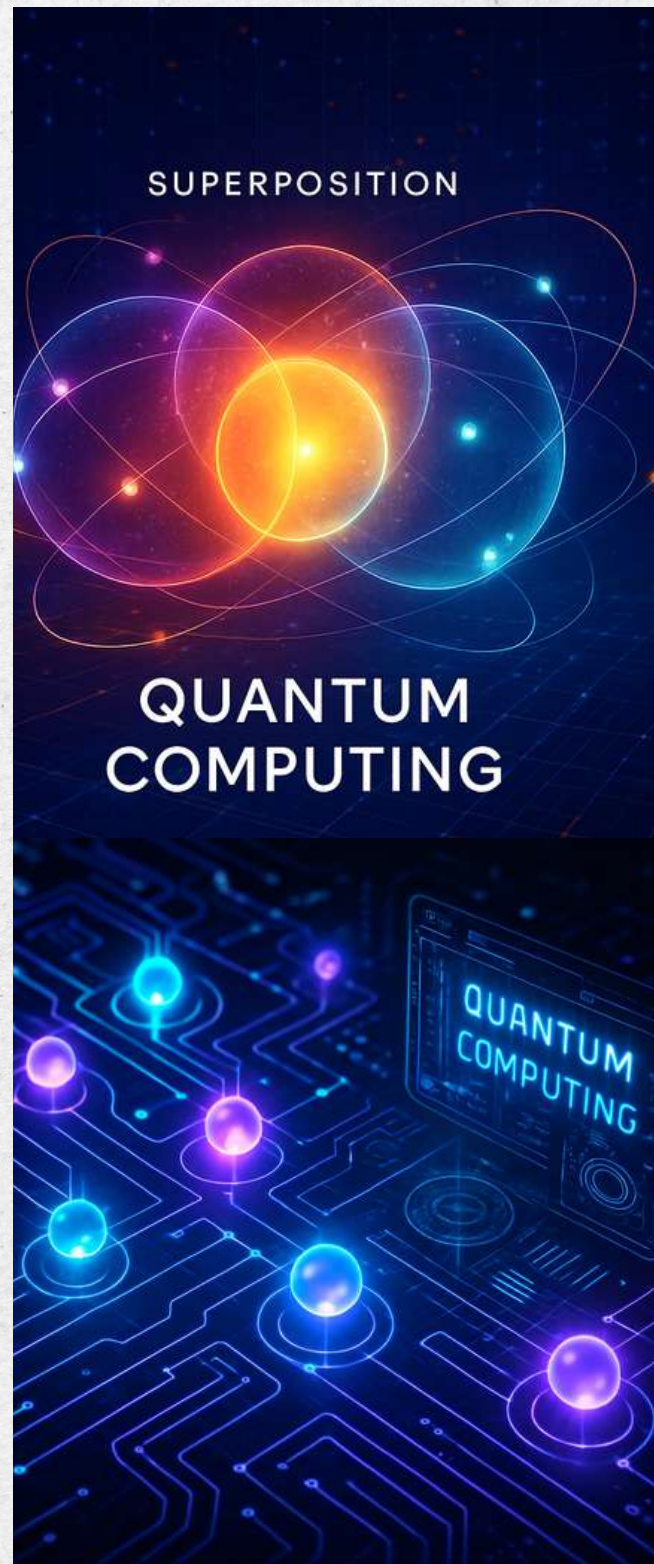
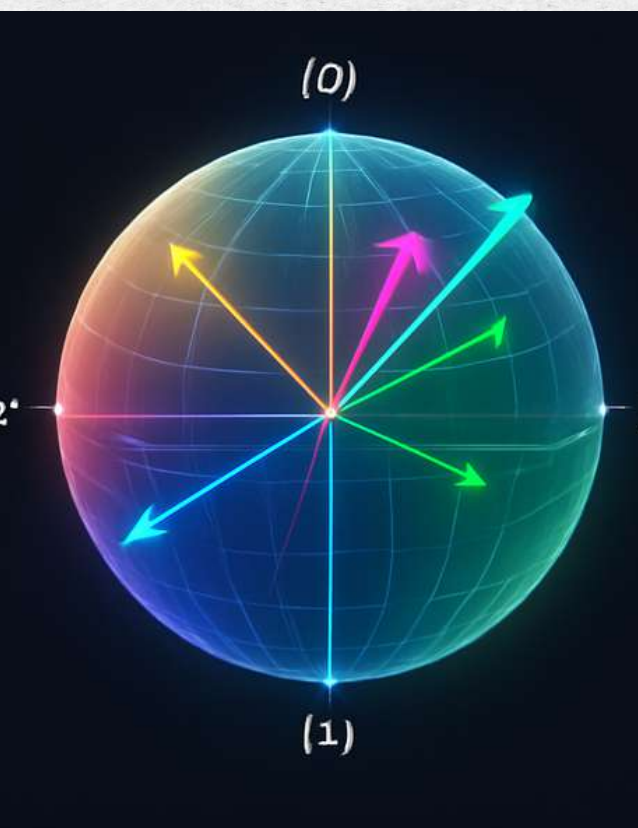
This unique property allows quantum computers to process a vast amount of information simultaneously,

For example, while 2 classical bits can represent only one state at a time (00, 01, 10, or 11), 2 qubits can represent all four states at once. This exponential growth is what makes quantum computers so powerful.

"A single qubit can hold much more information than a classical bit, and with each added qubit, the computing power grows exponentially."

(ii). Superposition – The Power of Being in Many States

Superposition is one of the most fascinating and fundamental concepts in quantum computing. Unlike classical bits, which exist as either 0 or 1, a quantum bit, or qubit, can exist in multiple states at the same time. This means a qubit can be 0, 1, or both 0 and 1 simultaneously until it is measured.



In simple terms, superposition enables quantum algorithms to examine many potential solutions at the same time, giving quantum computers a head start compared to classical machines that must check each possibility one by one.

(iii).Entanglement – Quantum Connections Beyond Space

Entanglement is one of the most extraordinary and mysterious principles in quantum computing. It describes a phenomenon where the quantum state of two or more qubits becomes deeply linked, meaning the state of one qubit will instantly influence the state of another, no matter how far apart they are. If you measure one entangled qubit, the outcome instantly determines the state of the other—like two magic coins that always match no matter the distance between them.



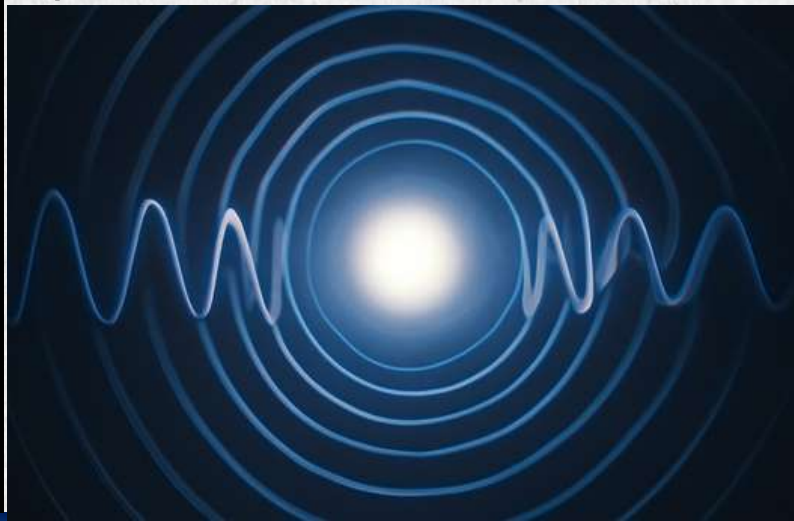
IN SHORT:-

"Quantum entanglement is a mysterious link between qubits where the state of one instantly affects the other, regardless of distance."

3. Quantum Gates – The Basic Building Blocks of Quantum Circuits

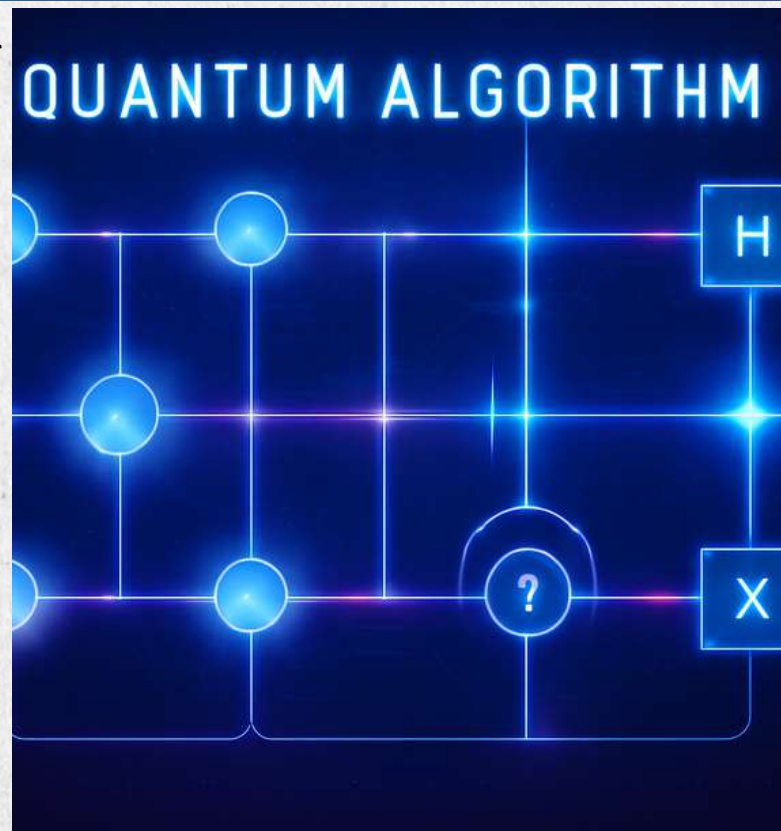
Quantum gates are the fundamental operations that manipulate qubits, enabling quantum computers to perform complex calculations. Just like classical logic gates (AND, OR, NOT) control bits in traditional computers, quantum gates control qubits, but with much more powerful capabilities thanks to quantum mechanics.

Quantum gates are represented as unitary matrices that transform the state of qubits through precise rotations and flips on the Bloch sphere, a visual representation of a qubit's state.



4. Quantum Algorithms – Unlocking the Power of Quantum Computers

Quantum algorithms are special sets of instructions designed to run on quantum computers, using quantum phenomena like superposition and entanglement to solve problems far faster than classical algorithms. Unlike traditional computers that process options one by one, quantum algorithms can explore many possibilities simultaneously.



>Here are the names of different quantum algorithms:-

- *1. Grover's Algorithm*
 - *2. Quantum Fourier Transform (QFT)*
 - *3. Deutsch–Jozsa Algorithm*
 - *4. Bernstein–Vazirani Algorithm*
 - *5. Simon's Algorithm*
 - *6. Quantum Phase Estimation*
 - *7. Variational Quantum Eigensolver (VQE)*
 - *8. Quantum Approximate Optimizations*
- etc....*

5. Quantum Computing in cryptography

Why Quantum Computing Matters in Cryptography

Classical cryptography relies on the hardness of certain mathematical problems (factoring, discrete logarithms, elliptic curves).

Quantum computers use qubits and quantum algorithms that can solve some of these problems exponentially faster than classical computers.

This means: Current encryption methods could be broken once large-scale quantum computers exist.



Cybersecurity applications

Broken Encryption: Once quantum computers scale, widely used encryption (RSA, ECC) becomes insecure.

Digital Signatures at Risk: Compromise of signatures means fake certificates, identity theft, and software tampering.

6. Quantum Computing in Healthcare

Revolutionizing medicine and Genetics

Quantum computing is poised to transform healthcare by enabling breakthroughs in areas that are currently beyond the reach of classical computers. One of the most promising applications is in ***drug discovery***. Quantum computers can simulate the complex molecular interactions of potential drug compounds with high accuracy, drastically reducing the time and cost involved in bringing new medicines to market.



Traditional computers struggle with the sheer complexity and scale of biological systems. Quantum computers leverage their ability to handle multiple states simultaneously, making it possible to solve optimization problems and simulate proteins and molecules more efficiently.

7. Quantum Computing in Artificial Intelligence & Machine Learning

Quantum computers can process and analyze massive datasets simultaneously, uncovering correlations and patterns faster than classical approaches.

Quantum computing is making significant advances in artificial intelligence (AI) and machine learning (ML) by speeding up computations, enhancing data analysis, and enabling new types of algorithms, especially for high-dimensional and complex data problems.



Quantum Machine Learning Fundamentals

QML can handle massive datasets and extraordinarily complex problems that are nearly impossible for classical computers to process efficiently, especially in areas like image, speech, and pattern recognition.

8. Quantum Computing in Climate & Weather Prediction

Quantum computing is beginning to transform climate modeling and weather prediction by enabling highly complex simulations, improved data assimilation, and faster analysis, all of which are essential for understanding Earth's rapidly changing environment.

Climate Modeling:

Quantum computing can simulate large-scale climate systems—such as global weather patterns and ocean currents—with a level of speed and detail unattainable for classical computers

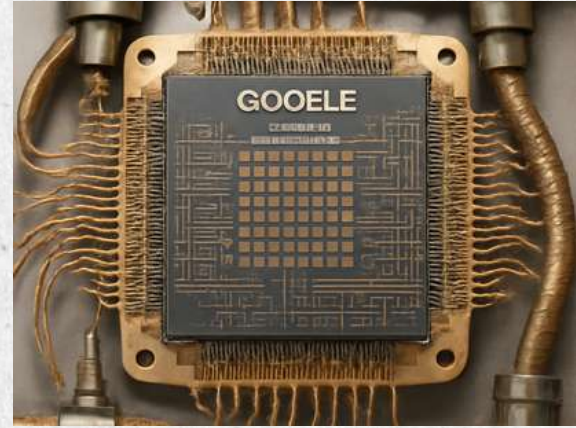


9. Current Development

9.1. The Global Race for Quantum Supremacy

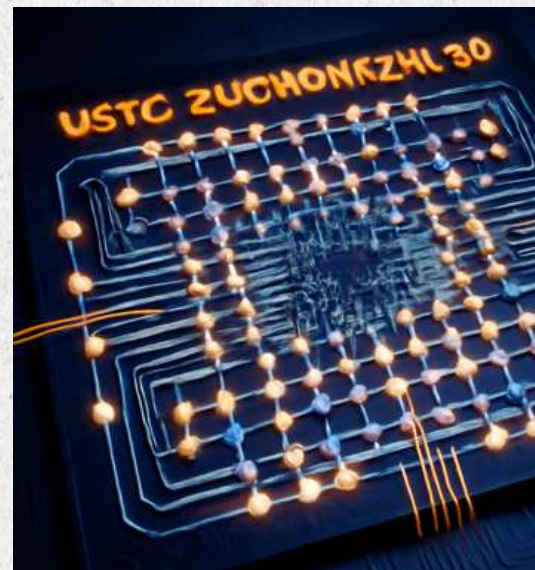
Google (Willow processor)

IN DECEMBER 2024, GOOGLE UNVEILED ITS WILLOW QUANTUM CHIP WITH 105 SUPERCONDUCTING QUBITS, DEMONSTRATING A DRAMATIC REDUCTION IN ERROR RATES THROUGH INNOVATIVE ERROR CORRECTION.



China

CHINA'S EFFORTS ARE SPEARHEADED BY USTC'S ZUCHONGZHI 3.0 ANOTHER 105-QUBIT SUPERCONDUCTING SYSTEM. IT ACHIEVED A SIMILAR QUANTUM ADVANTAGE IN SAMPLING BENCHMARKS AND BENEFITED FROM CHINA'S SUBSTANTIAL STATE-BACKED INVESTMENTS AND STRATEGIC PROGRAMS LIKE



IBM

QUESS AND NATIONAL LABS

IBM IS PURSUING LARGE-SCALE, FAULT-TOLERANT QUANTUM SYSTEMS. THE COMPANY'S ROADMAP INCLUDES CONDOR — A PROCESSOR WITH OVER 1,000 QUBITS, AND LONG-TERM GOALS LIKE REACHING 100,000 QUBITS BY 2033. THEY EMPHASIZE OPEN ACCESS VIA QISKIT AND REAL-WORLD PROBLEM SOLVING



9.2. Leading Companies & Startups in Quantum Computing

Phasecraft (UK).

A leading quantum software startup, Phasecraft raised \$34 million to expand its team and operations. Their hybrid algorithms are already in use by organizations like BT and Johnson Matthey, and they anticipate reaching "quantum advantage"—practical outperforming of classical machines—by spring 2026



IonQ (USA).

Analysts recently upgraded IonQ with a "Buy" due to its strong patent portfolio, cloud-based quantum services, and \$1.6 billion cash reserve. The company may capture 15%–40% of the future quantum market by 2035

D-Wave (Canada).

Their new Advantage system, offering enhanced connectivity and efficiency, is now accessible via the Leap cloud platform. Despite past skepticism, D-Wave reported a 509% YoY revenue increase, though bookings declined.



9.3. Role of Governments & Research Labs

China

Leveraging its state-led model, China has invested upwards of \$15 billion in quantum science, organized through national labs and five-year plans, making quantum communications and computing a strategic priority

United States

The National Quantum Initiative (NQI) has fueled R&D since 2018. In 2025, lawmakers proposed the Quantum Sandbox initiative to accelerate near-term quantum applications across sectors like healthcare and energy. Texas also launched its own Texas Quantum Initiative to attract projects and workforce development

European Union (and UK)

The EU's Quantum Flagship, a €1 billion, decade-long research program, supports quantum hardware, communications, and sensing projects. EU is also deploying quantum machines across member states through EuroHPC and pushing post-quantum encryption [PostQuantum.comAnalytics Insight](https://www.postquantum.com/analytics/insight).

The UK's long-term strategy includes a multi-billion-dollar commitment, a national lab, and initiatives like the Quantum Skills Taskforce—gearing up for a "Q-day" when encrypted data may become vulnerable

India

Approved in 2023, India's National Quantum Mission allocates ₹6,000 crore (\$730 million) to quantum tech through 2030. Four "T-Hubs" have been established at premier institutions (IISc, IIT-Madras, IIT Bombay, IIT Delhi).

10. Quantum Hardware vs Quantum Software

Quantum Hardware

Key Challenges:

- ❄️ **Cryogenic Cooling:** Most hardware needs -273°C to function.
- 📦 **Qubit Stability (Decoherence):** Qubits lose their quantum state in microseconds.
- 🔧 **Error Correction:** Millions of physical qubits may be needed for just 1 logical qubit.
- 🏗️ **Scalability:** Going from 100 to 100,000 qubits isn't linear

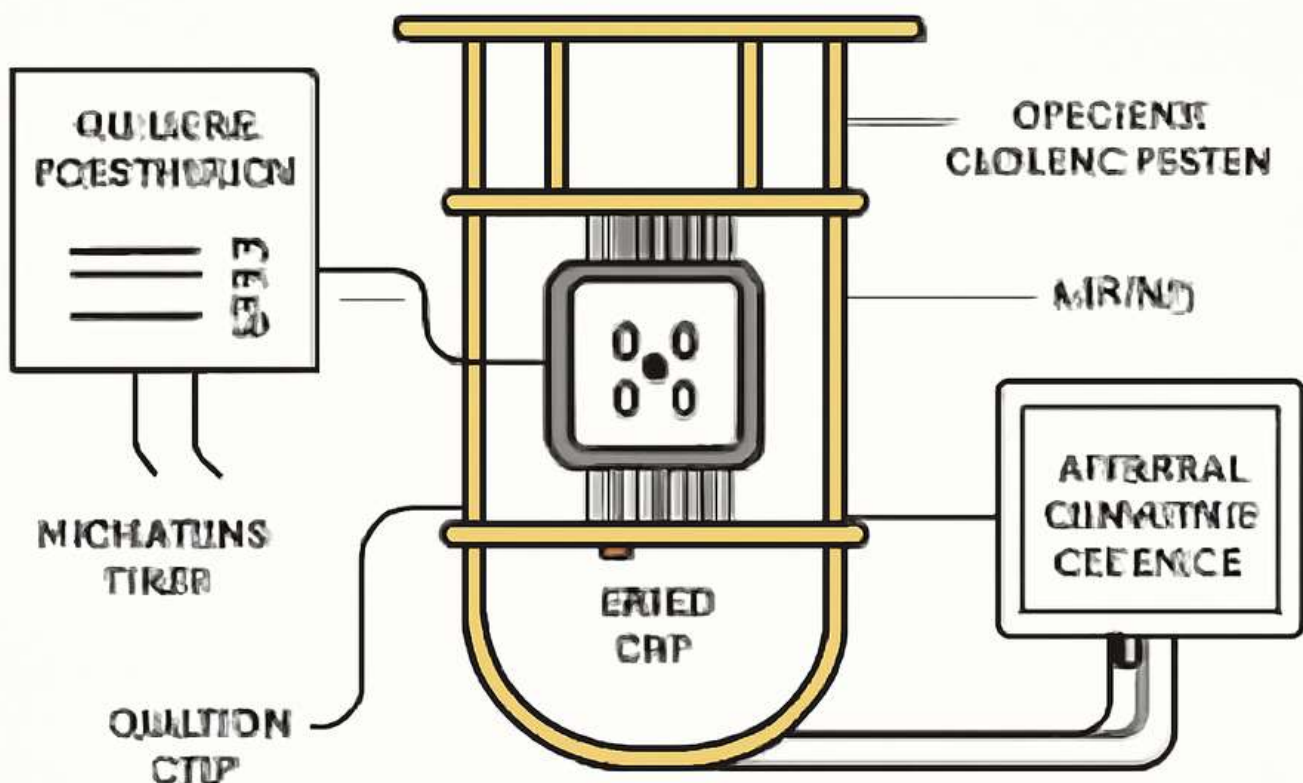
VS

Quantum Software

Key Challenges:

- 💻 **Algorithm Complexity:** Quantum logic is fundamentally non-intuitive.
- 🔍 **Hardware-Specific Optimization:** A good algorithm for IBM might fail on IonQ.
- 🤝 **Classical Integration:** Needs to coexist with traditional HPC systems.

QUANTUM HARDWARE



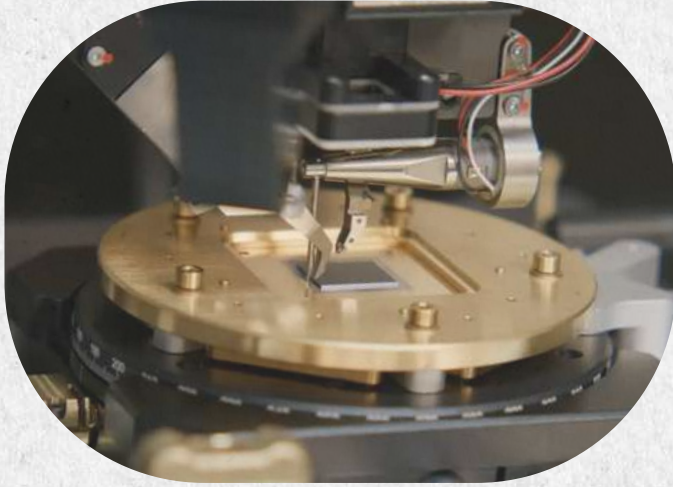
11. Future Possibilities & Challenges:

11.1 *Future of quantum computing:*

- Commercialization Growth – More companies will start offering quantum computing services via cloud platforms.
- Improved Hardware – Qubits will become more stable (less noise, longer coherence times).
- Error Correction – Progress in quantum error correction will make large-scale computations possible.
- Hybrid Computing – Quantum + classical systems will work together for solving complex problems.
- Industry Impact – Big impact expected in cryptography, drug discovery, materials science, optimization, and AI.
- Quantum Supremacy Expansion – More practical demonstrations beyond Google's 2019 milestone.
- Global Race – Countries (USA, China, EU, India) will invest heavily to gain leadership in this field.
- Long-Term Vision – In 10–20 years, quantum computers may outperform classical ones in many fields.



11.2 Key Challenges :



- **Stability(Decoherence)**

Qubits lose their quantum state very quickly due to external noise and vibrations. Maintaining coherence requires extremely low temperatures and isolation.

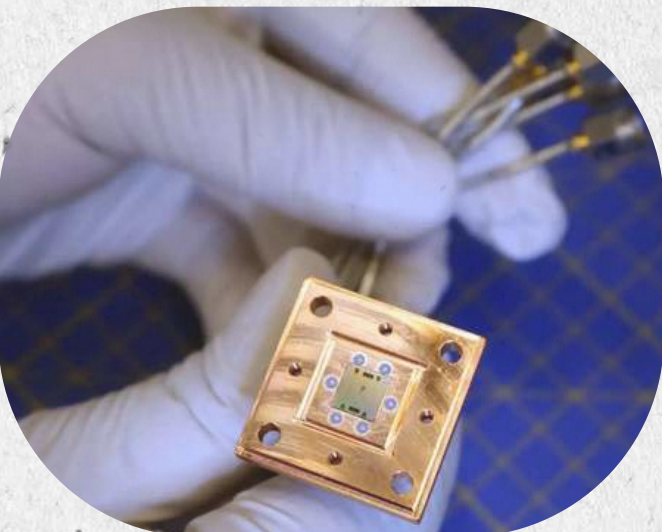
- **Scalability**

- Current quantum computers have limited qubits (tens to hundreds).
- Scaling to thousands or millions of qubits for practical applications is difficult due to hardware complexity and cost.



- **Error Correction**

- Qubits are highly error-prone (due to noise, interference, imperfect control).
 - Quantum error correction requires many extra qubits to protect a single logical qubit.
 - Increases hardware demands significantly.



12. ⚖️ Ethical Concerns in Quantum Computing



Privacy:

- Risk of breaking today's encryption.
- Who controls access to quantum-secure systems?



Misuse:

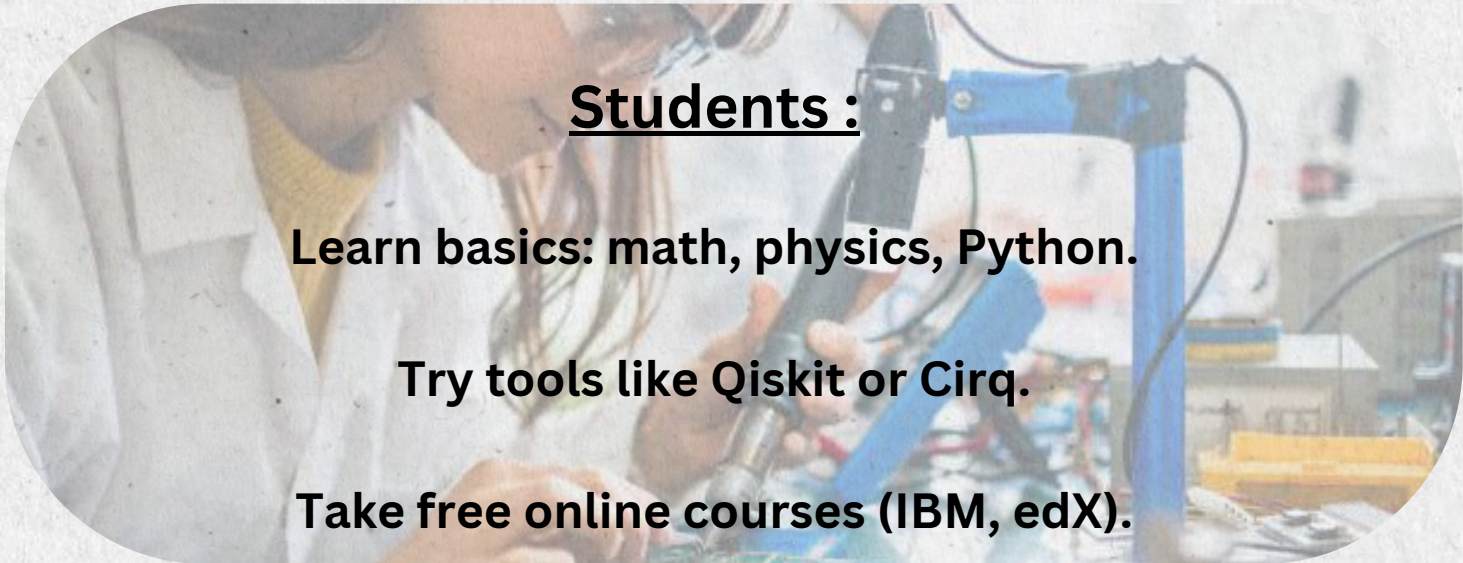
- Potential use in cyber warfare.
- Open algorithms could be exploited.



Inequality

- “qntum divide” between rich and poor nations.
- Benefits may stay limited to big corporations.

13. OPPORTUNITIES FOR STUDENTS & RESEARCHERS (HOW TO START LEARNING)



Students :

Learn basics: math, physics, Python.

Try tools like Qiskit or Cirq.

Take free online courses (IBM, edX).



Researchers

Explore algorithms, cryptography, materials.

Join global projects & internships.

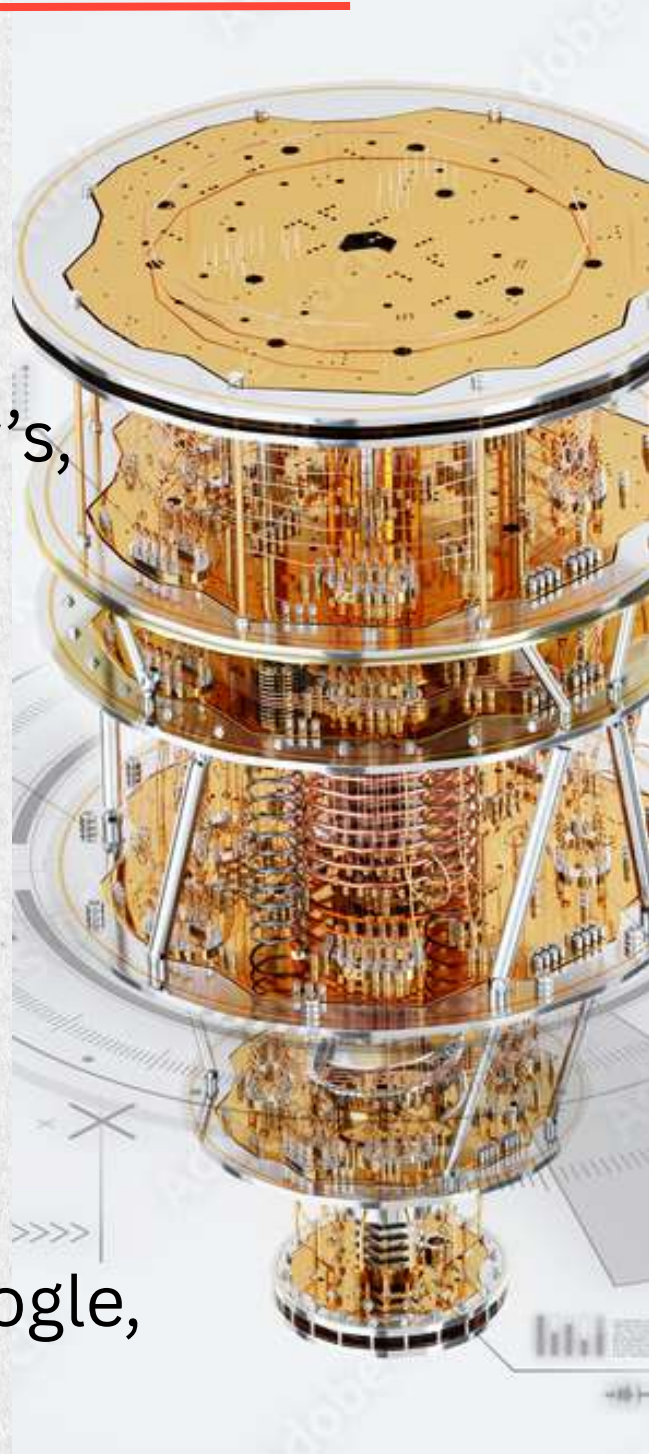
Apply for grants and lab collaborations.

Quantum computing is still in its early stages, but students and researchers who begin today will be at the forefront of tomorrow's breakthroughs."

14. What to includes:

Quick review of quantum computing's evolution:-

- Origins in quantum mechanics
- Key breakthroughs (Shor's, Grover's)
- Hardware and software progress
- Applications across industries
- Mention key players (Google, IBM, governments)
- Highlight current state: NISQ era + emerging applications



15. Recap of Our Quantum Journey

From Basics to Breakthroughs

Over the past chapters, we have journeyed from the foundations of quantum mechanics to the frontiers of quantum algorithms and applications. What once seemed like pure theory has unfolded into real-world innovations, reshaping the way we imagine computing, problem-solving, and the future of technology.

Future, Challenges & Ethics

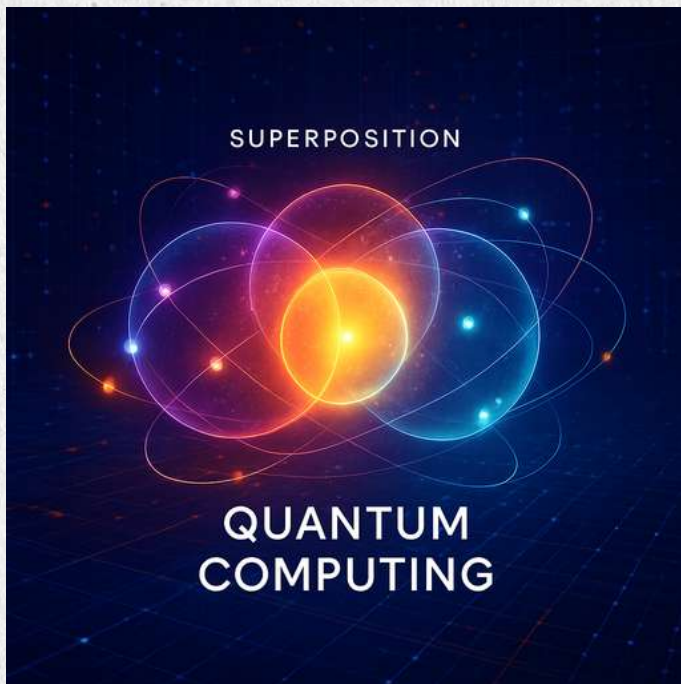
- Predictions say quantum computers could change entire industries within the next 10–20 years.
- But with great power comes great responsibility: ethical questions around privacy, misuse, and accessibility are already rising.
- We also explored how students, researchers, and curious minds can get involved today — because the future is being built now.



16.Final Thoughts

The Quantum Leap Ahead

As we reach the end of our journey through the world of quantum computing, one thing becomes clear: we're standing at the edge of a technological revolution.



Quantum computing is no longer just a theoretical concept locked inside physics textbooks or research labs. It's becoming real — and fast. From the way we secure our data to how we design new medicines, forecast the climate, and even rethink artificial intelligence, quantum computing has the power to reshape our future.

Student Coordinators



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