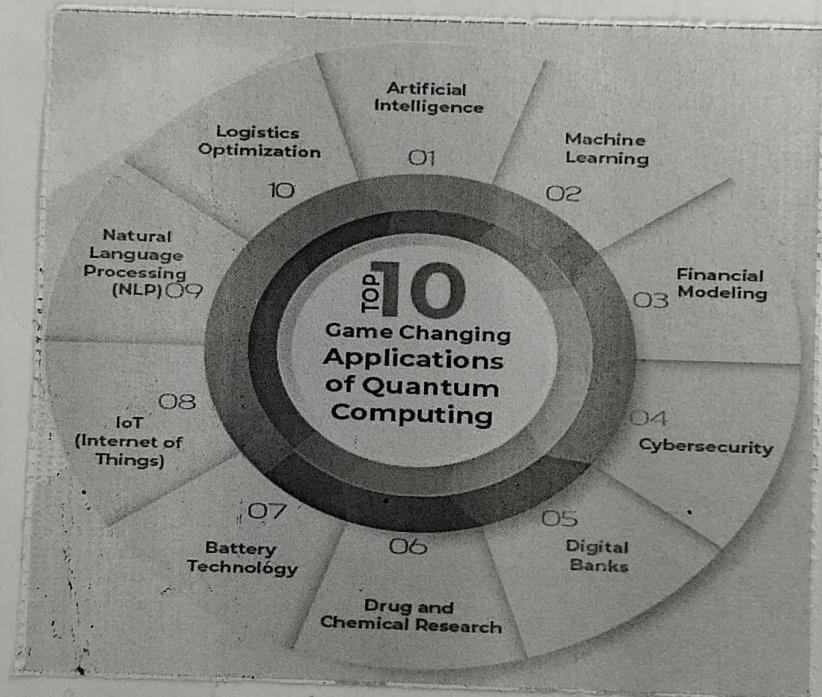


## \* Real-world application domains:-

Quantum technologies are increasingly moving from theory to real-world application. These technologies, exploit principles of Quantum mechanics - such as Superposition, entanglement, and Quantum tunneling - to perform tasks that classical systems struggle with or cannot do at all.

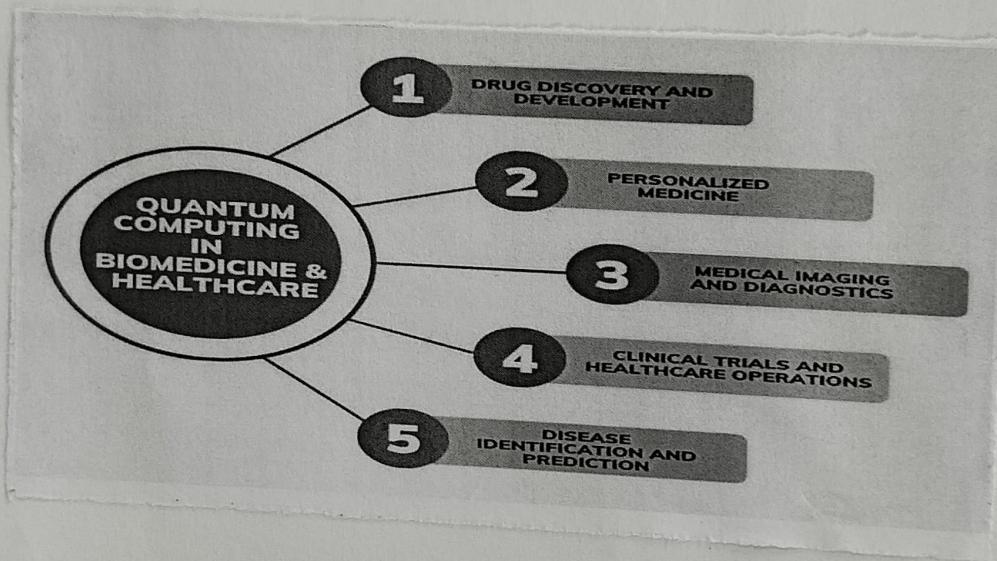


## \* Applications of Quantum Computing

\* Domains:-

(i). HEALTH-CARE:-

→ Drug-discovery:- drug discovery is one of the most promising real-world applications of quantum technologies. The process of discovering new drugs involves simulating complex molecules and chemical reactions - tasks that are extremely difficult and time-consuming for classical computers. Quantum Computers offer a revolutionary approach.



\* The potential Role of Quantum Computing in Biomedicine and healthcare.

⇒ Quantum Computing has the potential to transform drug discovery by simulating complex molecular structures and chemical reactions interactions with unprecedented accuracy. Classical Computers struggle with these complex calculations.

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due to the enormous number of possible configurations in large molecules. Companies like IBM, Google, and D-Wave, as well as biotech firms like Biogen and Gilead, are exploring this for faster drug development.

Quantum Computing can aid in optimizing clinical trials by selecting ideal patient groups and predicting outcomes. In the future, quantum-enhanced drug discovery could accelerate responses to pandemics and rare diseases like.

\* why Quantum Computing for Drug-discovery.

#### (i). Molecular-Simulation.

Molecules follow the laws of quantum mechanics. Quantum computers can naturally model these behaviours.

- Simulate interactions between atoms and molecules
- predict molecular properties and binding affinities.
- Understand reaction mechanisms at the quantum level.

#### (ii). Speed & Accuracy:-

- Faster Screening of drug Candidates.
- Better prediction of side effects, and efficacy.

#### (iii). Reduction in Cost & Time:-

Traditional drug development takes 10-15 years and billions of dollars. Quantum-enabled simulations could significantly shorten R&D cycles.

#### \* Current Applications & progress:-

1. Protein folding & Target Interaction.

2. Chemical Reaction - Simulation
- modeling how a candidate drug behaves in the human body.
- e.g. - BASF and Zapata Computing work on reaction pathway predictions.

Table :- Companies & Research Labs Involved.

Organization	Contribution
IBM - Quantum	Simulated small molecules like LiH & BeH <sub>2</sub> . Collaborating with biotech firms.
Google Quantum AI	Simulated basic molecules using 8y Carrera quantum processor.
D-Wave	Exploring quantum Annealing for molecule optimization.
Astra-Zeneca	Collaborating with Quantinuum and Cambridge Quantum for drug design.
Roche & Boehringer Ingelheim	partnering with quantum startups to simulate complex molecules.
ProteinQure	uses quantum computers for protein-drug interactions and optimization.

### \* MATERIAL-SCIENCE :-

Quantum technologies are transforming material science by enabling scientists to discover and design new materials with unprecedented accuracy and speed. Quantum computers

and Quantum Simulation help model complex atomic interactions that are too difficult for classical computers to handle.

### \* why use Quantum - Technologies in Material - Science?

#### [1] Quantum systems obey quantum rules:

Traditional materials modeling often relies on approximations. Quantum computers simulate matter at the quantum level - electrons, bonds, energy states - without such approximations.

#### [2]. Designing from the atom up:

- Quantum technologies allow researchers to:
- Discover new superconductors.
- Design stronger, lighter alloys.
- Engineer better batteries, semiconductors & crystals.

Quantum computing enables the accurate simulation of material behaviour at the atomic level, which is difficult for traditional systems to achieve. This opens the door to discovering new materials with tailored properties for use in industries such as energy, electronics, and aerospace. For instance, researchers could design more efficient superconductors, lighter and stronger metals, or advanced polymers for biodegradable packaging. Quantum simulations allow scientists to model and tweak atomic structures before they are physically created, saving time and resources.

The development of better battery-like solid-state or lithium-air types - can also be accelerated through Quantum methods. Solar panel efficiency could be significantly improved by finding materials that better convert sunlight into electricity. High-performance computing already assists in these areas, but quantum systems bring the necessary scale and precision. The ability to model quantum effects directly makes quantum computing an ideal tool for material science. It may soon lead to breakthroughs in sustainability, electronics, and communication to simulate battery materials.

#### \* Logistics and Optimization:

Quantum computing is set to revolutionize logistics and optimization problems that are computationally intensive for classical systems. These include route optimization, supply chain management, inventory forecasting, and delivery scheduling. Quantum algorithms, like the Quantum Approximate Optimization Algorithm (QAOA) are being explored to solve such combinatorial problems more efficiently.

Companies like DHL & FedEx are investigating quantum solutions to reduce delivery times and costs, especially under variable constraints, like traffic & weather. In manufacturing, quantum systems can optimize production like workflows & resource allocation. Airlines could use quantum

methods to improve aircraft scheduling and crew assignments. As logistics grow more complex with global trade, the ability to find near-optimal solutions rapidly becomes a competitive advantage. Classical computers reach limitations quickly with these NP-hard problems, whereas quantum systems scale better.

### \* Quantum-Sensing and precision timing:

Quantum sensing harnesses the unique properties of quantum systems - such as superposition, entanglement, and quantum tunneling - to detect and measure physical quantities with extreme precision. Unlike classical sensors, which are limited by thermal noise and other environmental interferences, quantum sensors exploit the sensitivity of quantum states to detect incredibly subtle changes in environmental parameters. These include magnetic fields, gravitational anomalies, electric fields, acceleration, and rotation. As a result, quantum sensing is opening up new frontiers in areas that demand ultra-high sensitivity accuracy.

For example, quantum sensing can detect minute changes in magnetic and gravitational fields, enabling earlier earthquake detection or underground resource mapping. In healthcare, they may allow for more accurate brain scans or non-invasive diagnostics. Precision timing, powered

by quantum clocks, ensured ultra-accurate synchronization, essential for global positioning systems (GPS), financial trading networks, and secure communications.

One of the most promising applications of quantum sensing is in geophysical and geological surveying. For instance, Quantum gravimeters can detect underground voids, mineral deposits, and water sources by sensing tiny variations in gravitational fields. This has significant implications for oil and gas exploration, mining, archaeology, and even tunnel detection for military use. Similarly, Quantum magnetometers can detect minute changes in magnetic fields, which can be used to monitor volcanic activity or predict seismic disturbances - enabling early-earthquake warning systems that could save lives.

In the medical field, Quantum Sensors are expected to revolutionize diagnostic techniques. Technologies such as Quantum enhanced magnetoencephalography (MEG) and Magneto Cardiography (MCG) could allow for highly detailed non-invasive monitoring of brain and heart activity. A wide range of applications: GPS and satellite navigation, which require synchronized clocks to triangulate location; high-frequency financial trading, and quantum-secure communication networks, which rely on exact timing to distribute quantum keys securely.

in defense and aerospace, Quantum Sensors play a pivotal role in developing inertial navigation systems.

They are likely to be integrated into consumer-grade electronics. Future smartphones, wearables and health devices could incorporate quantum-enhanced sensors for more capabilities and accurate fitness tracking, health diagnostics, and even environmental monitoring.

In this, Quantum Sensing and precision timing stand to redefine the limits of measurement and detection across multiple sectors.

### INDUSTRIAL CASE-STUDIES:

#### IBM :-

IBM has been one of the earliest and most active players in the Quantum Computing industry. Its flagship platform, IBM Quantum, provides cloud-based access to quantum processors, allowing researchers, students, and developers to experiment with quantum algorithms. IBM introduced the Qiskit open-source framework to encourage quantum programming and research collaboration.

Their IBM Quantum System One, the world's first integrated Quantum System for commercial use, has been deployed in multiple locations globally. IBM's roadmap is transparent and ambitious - they aim to scale Quantum

hardware from hundreds to thousands of qubits using error-Corrected quantum processor. IBM is also making progress in quantum error detection and correction, recently demonstrating the use of Quantum LDPC (Low-Density Parity-Check) Codes, which are essential for building reliable, large-scale quantum systems. Their 2023 milestone - the 433-qubit "Osprey" processor - showcases their hardware scalability. By 2025, IBM plans to release Condor, a processor with over 1,000 qubits, further pushing the envelope.

In parallel, IBM continues to enhance Qiskit Runtime, an execution environment that optimizes quantum circuit performance through advanced compilation and error mitigation. IBM also publishes a transparent quantum roadmap, updated annually, which guides developers, educators, and researchers globally.

Notably, IBM is collaborating with industries such as healthcare, finance, and chemicals to apply quantum computing to real-world challenges, including molecule simulation, portfolio optimization, and materials discovery. They have also partnered with governments and academic institutions to develop the Quantum workspace, showcasing a commitment not only to technology but also to ecosystem building.

## [II]. GOOGLE :-

Google captured global attention in 2019 when it claimed quantum supremacy - demonstrating that its 53-qubit processor "Sycamore" could perform a specific computation in 200 seconds that would take the best classical supercomputer thousands of years. While the particle value of the task was debated, the experiment marked a significant milestone in quantum hardware progress.

Google Quantum Research division is focused on building a fault-tolerant quantum computer with 1 million physical qubits. They are exploring use cases in AI, optimization, and quantum chemistry. Google is also investing heavily in error correction techniques to make large-scale quantum computing viable.

Google is also a quantum AI hybrid-model, where classical and quantum systems work in tandem to accelerate tasks like data clustering, pattern recognition, and neural network training. Their Quantum AI Campus in Santa Barbara is home to cutting-edge labs where innovations in cryogenics, qubit calibration, and quantum firmware are rapidly advancing. Google's team has made important strides in quantum error suppression through techniques like zero-noise extrapolation and quantum benchmarking. Their recent work on surface codes and logical qubits

Shows measurable progress toward fault tolerance.

Their bold long-term vision includes integrating Quantum Computing with classical systems and cloud infrastructure.

As a tech leader, Google's work is influencing academic and industrial agendas worldwide, accelerating innovation and competition in the Quantum Space.

Beyond hardware, Google actively contributes to the Open-Source Quantum Community through Cirq and TensorFlow Quantum, allowing AI researchers to explore quantum-enhanced machine learning models. Google's Quantum Computing Service aims to eventually offer practical applications through Google Cloud, bringing enterprise-level quantum access to mainstream business. Their partnerships with institutions like UC Berkeley and ETH Zurich are advancing research in Quantum Simulation and Condensed matter physics. With a strong emphasis on long-term scalability, Google's approach balances scientific rigor with practical engineering. Its bold goal—achieving a commercial-grade, error-corrected quantum computer this decade—drives much of the industry's pace.