

Transformation

Quantum dictionary, part 1: Decoding the fundamentals

21 October 2026

Key takeaways

- What is quantum computing? How does it work? What is a qubit? And when will quantum reach its full potential? Quantum computing challenges our intuition and our understanding of what computers can do. In this two-part dictionary series, we decode key terms behind what could be the next major technological revolution.
- Qubits are the basic building blocks of quantum computers, harnessing properties such as superposition and entanglement to process information. However, qubits are highly sensitive to their surroundings where disturbances can lead to errors in quantum computation, making error correction a key challenge for building quantum computers.
- There is no single approach to building a quantum computer. Researchers and companies are pursuing a range of qubit technologies, from neutral atoms and photons to spin, superconducting, topological and trapped-ion qubits, while quantum computing itself is likely to increasingly work alongside classical computing and AI.

First, let's lay the groundwork...

Quantum computing

Quantum computing uses qubits and quantum properties such as superposition (defined later on) to perform complex calculations and solve certain problems faster than classical computers.¹ From a practical perspective, quantum computing could be used to tackle problems related to optimization, machine learning, simulation and factorization across a range of sectors, including autos and logistics, financial services, energy and climate, health and life sciences and national security.

Current quantum computers can perform 'just' thousands of quantum operations. As the technology advances from thousands to millions, billions and eventually trillions of operations, quantum computers could begin to have commercial applications.

- Millions: Financial services and security could experience some of the first use cases, such as threat detection, fraud prevention, derivatives pricing, bond trading and arbitrage.
- Billions: Quantum could help power AI through advanced data generation capabilities.
- Trillions: Quantum chemistry applications could emerge, including drug discovery, battery simulation and materials discovery.

These are the publicly known applications, according to Oxford Quantum Circuits (OQC). And as quantum computing capabilities improve, some of these use cases could emerge sooner than anticipated.

Now, we'll tackle the core concepts...

Qubits

Qubits (quantum bits) are a quantum computer's basic unit of information. They can exhibit quantum properties such as superposition and entanglement (which we elaborate on below) — properties fundamental to quantum computing.

Quantum gates manipulate the state of qubits, much like logic gates manipulate bits in classical computers. Despite the name, a quantum gate is not a physical object, but rather an operation applied to a quantum system that changes its state.

From physical to logical qubits

Physical qubits are the foundation of a quantum computer's hardware. However, they are highly susceptible to error. To address this, multiple physical qubits can be structured together to encode a logical qubit, allowing errors to be detected and corrected

¹ Schneider, J., & Smalley, I. (2025, June 10). *What is quantum computing?* IBM.

and making the stored quantum information more reliable. In recent years, according to BofA Global Research, logical qubits have become a greater focus for quantum computing companies.

Entanglement

Entanglement is a condition where two or more qubits become linked so that their states are correlated, regardless of distance (Exhibit 1). It allows quantum computers to process information in ways that can be difficult or impossible for classical computers.

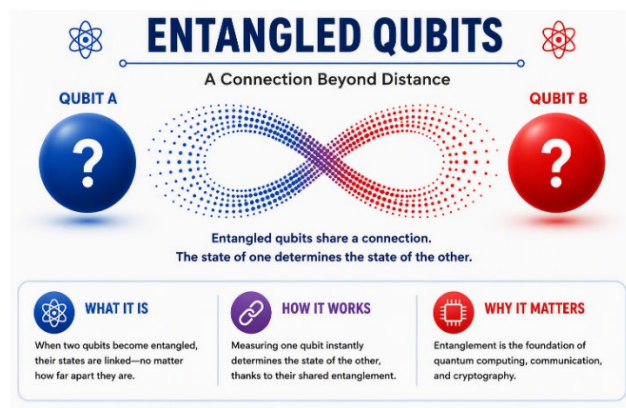
So, how does it work? Suppose we have two photons that have opposite polarizations (the orientation of their light waves). Before measurement, neither has a definite polarization. When one is measured as horizontally polarized, the other will be vertically polarized when measured in the same basis, wherever it is. When measured separately, they appear to be random, but when compared, they are correlated (Exhibit 2).

The challenges

Once created, entanglement must be protected from decoherence (where interactions with the environment destroy quantum correlations). Maintaining entanglement over long distances is another challenge. Photons traveling through optical fiber can be absorbed or scattered, making long-distance quantum communication difficult.² Quantum repeaters aim to overcome this challenge by extending entanglement across a series of shorter links.

Exhibit 1: Entanglement is a state where at least two qubits become correlated

An infographic of entangled qubits

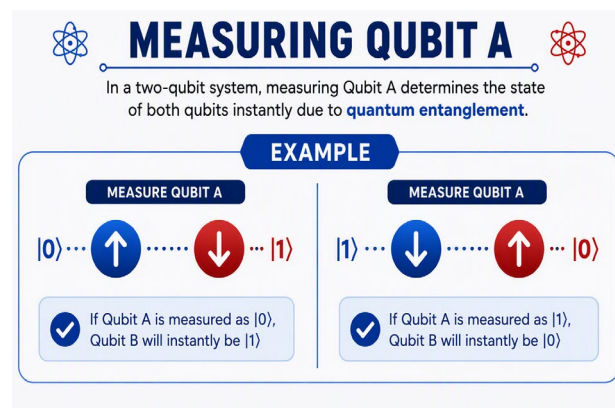


Source: BofA Global Research

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Exhibit 2: Measuring one qubit in an entangled pair instantly determines the state of the other, no matter the distance

An example of what entanglement means for qubit measurement



Source: BofA Global Research

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Superposition

Unlike a classical bit, which can be one of two states (0 or 1), superposition allows a quantum system to exist in multiple states or configurations at the same time (Exhibit 3). For example, a qubit can exist in the 0 state, the 1 state or any state that is a combination of 0 and 1.³

A quantum system can maintain a superposition until it is observed or measured. Once measured, its superposition collapses into a single state. Another way of thinking about superposition is to imagine a sphere with the north pole representing zero and the south pole representing one. Other points on the surface of the sphere represent different superposition states. This allows us to: 1) represent complex forms of information; and 2) simulate atoms in a computer.

Schrödinger's cat

In 1935, physicist Erwin Schrödinger proposed a thought experiment to illustrate the strange implications of quantum mechanics. In this scenario, a cat, a radioactive substance that decays very slowly, and a Geiger counter are put together in a sealed box. According to quantum mechanics, the system can be described as a superposition in which the cat is both alive and dead until the box is opened. Once the box is opened and the system is observed, the superposition collapses into a single outcome.

² Rehman, M. (2026, May 11). *What is Quantum Entanglement?* Quantum Insider.

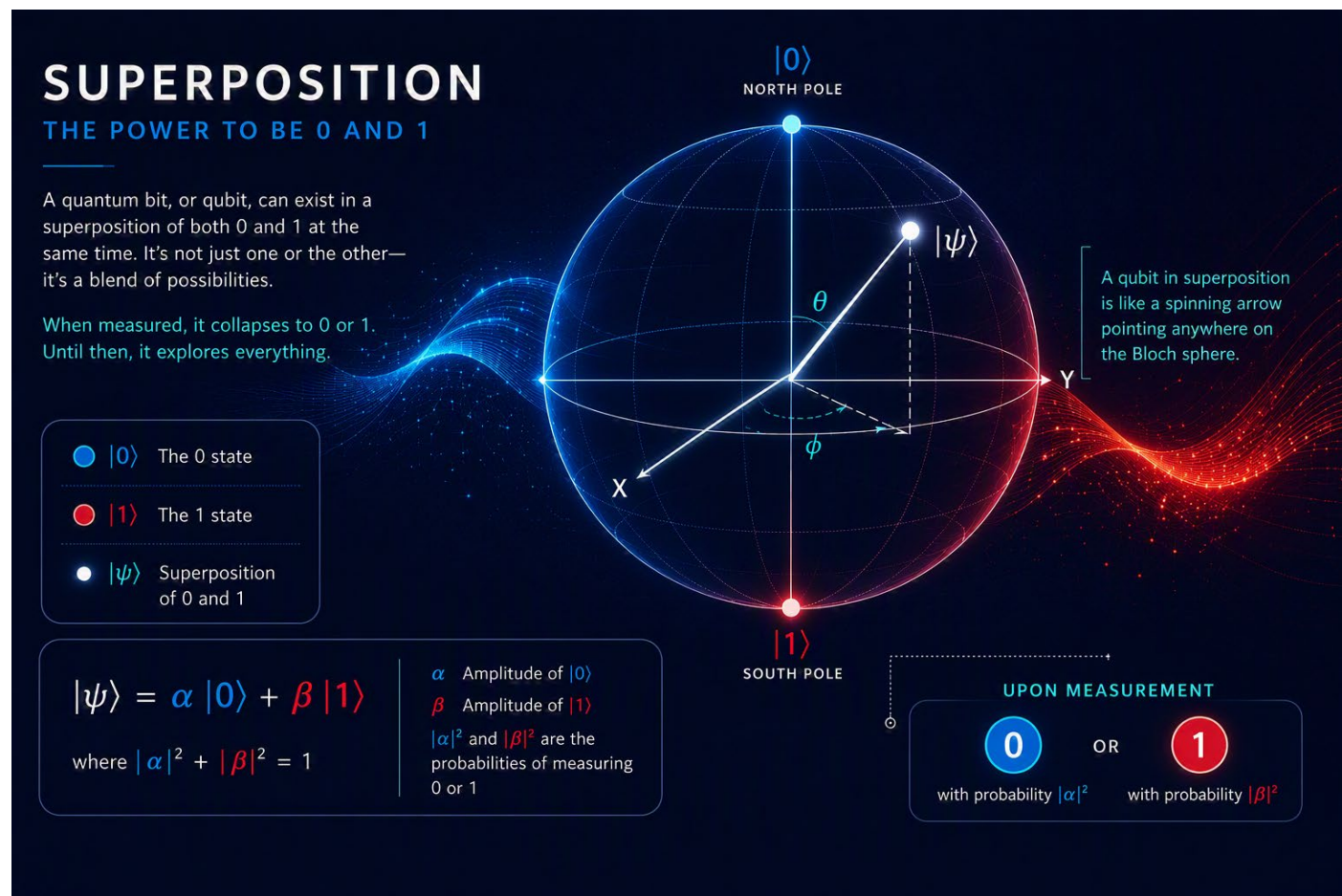
³ Microsoft. (n.d.). *Superposition*.

Enabling parallel computation versus classical computing

Superposition is a key attribute of quantum computing that allows for quantum parallelism, or the ability to perform multiple computations at the same time. Classical bits can only be in one of two states, 0 or 1. In contrast, a qubit can be in a superposition of 0 and 1, allowing a quantum computer to process multiple possible qubit states at once.⁴

Exhibit 3: Superposition is the condition where a qubit can exist in a superposition of 0 and 1

Illustrating the power of superposition



Source: BofA Global Research

Note: A Bloch sphere is a geometric representation of qubit states.

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Error rates and fidelity

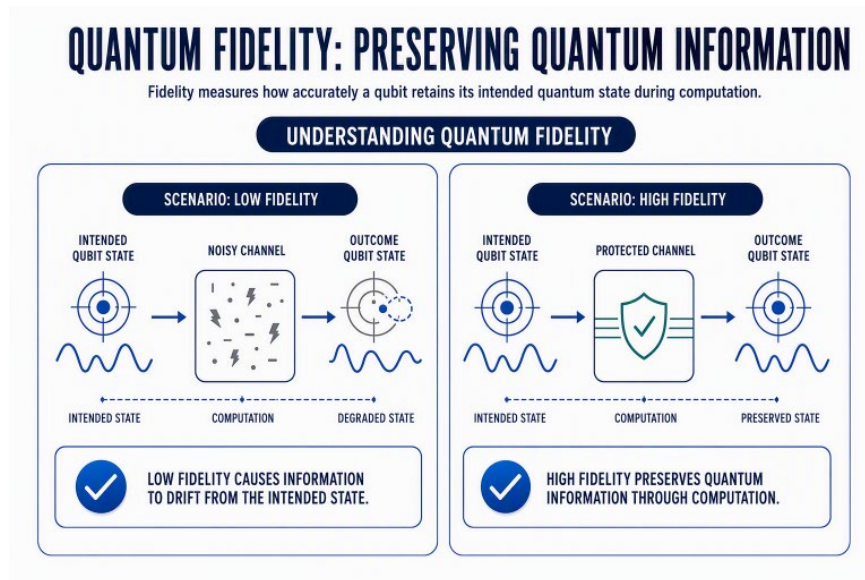
Fidelity is a measure of how closely a quantum state or operation matches what was intended (Exhibit 4). A higher fidelity generally means fewer errors.

Physical qubits are prone to errors. One way to address this is to combine multiple physical qubits to create a more reliable logical qubit. Quantum error correction (QEC) allows errors in the physical qubits to be detected and corrected, helping protect the information stored in the logical qubit.

⁴ Ibid.

Exhibit 4: Fidelity measures how accurately a qubit retains its intended quantum state during computation

Infographic showing the implications of high versus low fidelity



Source: BofA Global Research

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How does quantum error correction work?

At its simplest, QEC relies on redundancy, or storing information across multiple qubits so that errors can be detected and corrected.

Consider an example: suppose someone wants to send a message represented by 0. Instead of sending a single 0, the message could be repeated three times as 000, known as a codeword. If one bit were accidentally flipped from 0 to 1 during transmission, the recipient might receive 010. Because two of the three bits are still 0, the recipient could infer that the intended message was 000.

However, if two bits flipped, producing 110 or 011, the recipient could infer the wrong message. If all three flipped to 111, the recipient would have no way to know from the received codeword that errors had occurred.⁵ This approach is known as a repetition code and illustrates how redundancy can help protect information from errors.

Repetition codes are a simple form of error correction that can address bit-flip errors, where a 0 changes to a 1 or vice versa. More sophisticated QEC codes are needed to address other quantum errors, such as phase flips.⁶ Shor's code, developed by American theoretical computer scientist Peter Shor, uses nine physical qubits to encode one logical qubit and can correct one bit-flip error or one phase flip error, but it can't correct both types of errors at the same time. Meanwhile, Steane's seven-qubit code, developed by Oxford physicist Andrew Steane, can also correct both types of errors. It has the advantage of being fault-tolerant, meaning the error-correction process itself does not introduce additional errors.⁷

At what error level might we start seeing quantum advantage?

Some classical computing systems today operate with extremely high reliability, often described as having "17 nines" of fidelity (99.999999999999999%). By comparison, quantum computers currently achieve fidelity rates of around 99.9%. Gerald Mullally, CEO of OQC, has argued that quantum systems would need to add roughly three more nines of fidelity to achieve commercial relevance, or quantum advantage.

Noise and decoherence

Noise refers to unwanted disturbances that affect quantum systems and can lead to errors in computations (Exhibit 5). It can come from sources such as interactions with the environment, electromagnetic interference and temperature fluctuations. Coherence is a quantum system's ability to maintain its quantum properties, including superposition and entanglement. When coherence is lost through interactions with the environment, the process is known as "decoherence," causing the system to behave more classically (Exhibit 6).⁸

⁵ Microsoft Ignite. (n.d.) *Introduction to quantum error correction*.

⁶ Ibid.

⁷ Ibid.

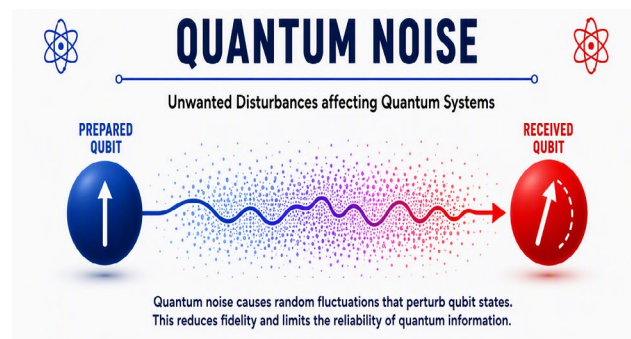
⁸ Quandela. (n.d.) *Quantum Decoherence*.

To fully control qubits for calculations and information transfer, they need to be carefully protected from their surroundings. External factors like noise, energy, changes in Earth's magnetic field, radiation from Wi-Fi or mobile phones or cosmic rays can interfere with the process. Even small disturbances can lead to decoherence, making it difficult to develop large-scale, fault-tolerant quantum computers.⁹

According to QuEra Computing, quantum noise can be mitigated through physical isolation of qubits, the development of more precise control techniques and quantum error correction, which helps detect and correct errors in physical qubits.

Exhibit 5: Noise refers to unwanted disturbances, e.g., interactions with the environment, that lead to errors in quantum computation

An infographic explaining quantum noise

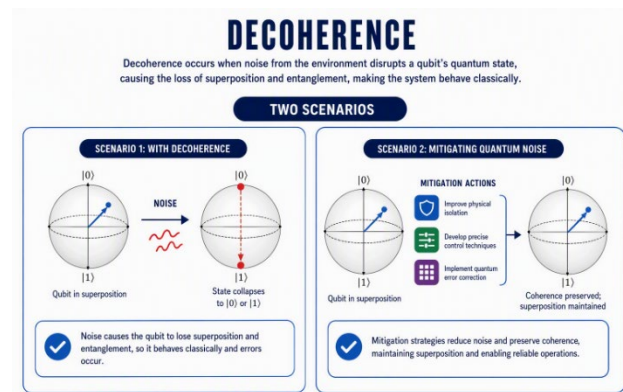


Source: BofA Global Research

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Exhibit 6: Decoherence is when qubits lose their key quantum properties, superposition and entanglement

An infographic of decoherence



Source: BofA Global Research

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Quantum processing unit (QPU)

Referred to as the brain of the quantum computer, the QPU is the core hardware where qubits reside and where quantum computations take place. QPUs rely on quantum behaviors like superposition and entanglement to tackle problems in areas such as cryptography, simulation and optimization. Just as a CPU (central processing unit) in classical computing contains multiple components, a QPU includes quantum gates (operations that manipulate qubits in a controlled way, similar to logic gates in classical computing) and interconnects, which enable communication between qubits and other quantum processors.¹⁰

Next, we'll look at broader computing architecture...

Heterogeneous computing

Heterogeneous computing refers to a future computing landscape likely combining classical and quantum computing, potentially unlocking more powerful, faster and cheaper compute and helping solve problems that classical computers cannot. According to BofA Global Research, AI and quantum computing could also converge and complement each other, enabling more transformative use cases.

Quantum modality

A quantum modality refers to the type of physical technology used to create and manipulate qubits. We discuss the modalities in greater depth in the following section.

Lastly, we outline qubit technologies...

Neutral atom qubit

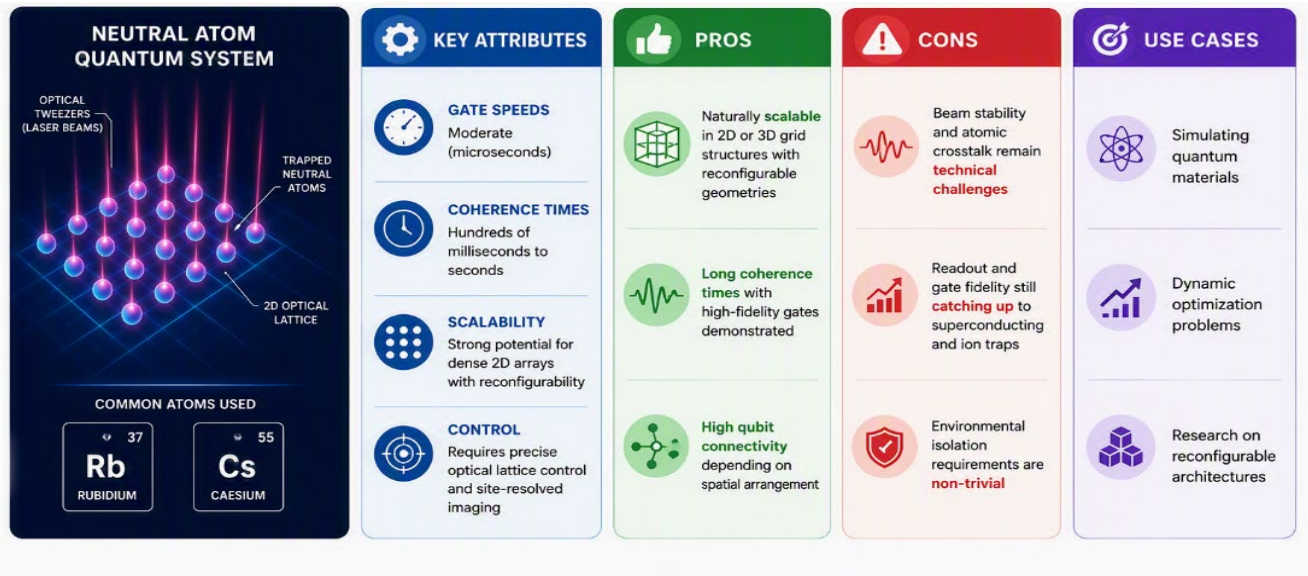
A quantum modality that uses individual atoms with no electrical charge as qubits (Exhibit 7). The atoms are held in place using focused lasers known as optical tweezers. Neutral atom qubit systems do not require atoms to be ionized, which means fewer energy constraints and potentially simpler cooling requirements. Atoms such as rubidium or cesium are typically used. The qubits are manipulated by changing the energy levels or positions of the trapped atoms using laser pulses.

⁹ QuEra. (n.d.) *Quantum Noise*.

¹⁰ SpinQ. (2025, January 16). *What does a Quantum Computer Look Like? Explain Key Parts*.

Exhibit 7: A quantum modality where atoms with a net electrical charge of zero are the foundation for qubits

Key features of neutral atoms



Source: BofA Global Research

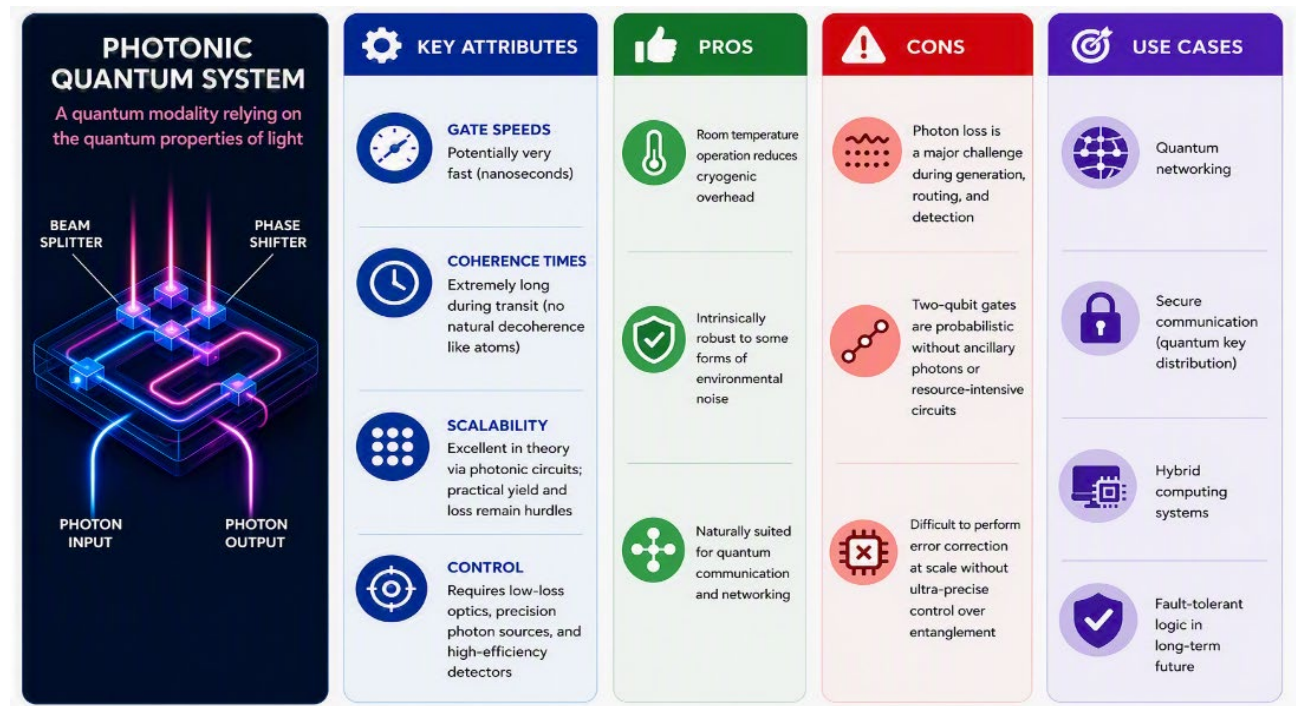
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Photonic qubit

A quantum modality that uses particles of light, known as photons, to carry quantum information (Exhibit 8).¹¹ Optical components such as beam splitters, which divide light along different paths, and phase shifters, which change the phase of light, can be used to perform quantum operations. Photonic quantum computers can use integrated photonic chips to manipulate photons and enable quantum logic.

Exhibit 8: A quantum modality relying on the quantum properties of light

Key features of photonic qubits



Source: BofA Global Research

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¹¹ Moore, J. (2025, March 28). *The 6 different types of quantum computing technology*. TechTarget.

Spin qubit

A quantum modality that uses the intrinsic spin of electrons or nuclei in solid-state materials, such as silicon or diamond. These spins can be manipulated using magnetic or electric fields, and their states are read using optical or charge-sensing techniques. Spin qubits are particularly appealing because they can leverage existing CMOS (complementary metal-oxide semiconductor; a technology to build processors) manufacturing infrastructure, making it easier to integrate them with conventional processors.

Superconducting qubit

A quantum modality in which electronic circuits create qubits. They are built using Josephson junctions, where two superconductors are separated by a thin insulating layer. Microwave pulses manipulate the qubits' quantum states to run computations.¹²

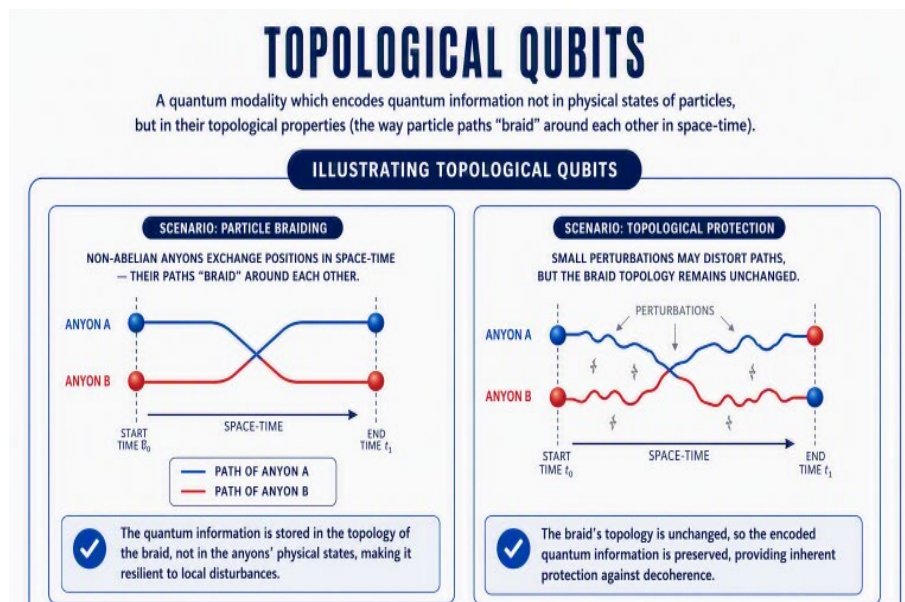
Specifically, a resistance-free current oscillates back and forth around a quantum loop. An injected microwave signal excites the current into superposition states.¹³ To enable this process, superconducting materials are cooled to near absolute zero (around 10-20 millikelvin) using dilution refrigerators, helping reduce thermal noise and maintain coherence.

Topological qubit

A quantum modality that aims to encode quantum information using topological properties rather than relying only on individual particle states (Exhibit 9). One way to think about this is through the paths certain quasiparticles take as they move around one another, creating "braids" in space-time. Because the information can depend on the overall pattern of these braids rather than small details of their paths, the approach is designed to be more resilient to certain disturbances.

Exhibit 9: Resilient to small perturbations but requires special quasiparticles not yet been conclusively demonstrated in nature

An infographic of topological qubits



Source: BofA Global Research

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Trapped-ion qubit

A quantum modality in which ions (electrically charged atoms) are held in place using electromagnetic fields. These ions act as the qubits and are controlled by the system with tightly focused laser beams.¹⁴ The qubits are held inside ultra-high vacuum (UHV) chambers.

¹² Ibid.

¹³ Simon Benjamin

¹⁴ Moore, J. (2025, March 28). *The 6 different types of quantum computing technology*. TechTarget.

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