# Quantum Computing: A Concise Introduction

Subjects: Quantum Science & Technology

Contributor: Brady D. Lund , Sakib Shahriar

Quantum computing is an emerging field in computing technology that harnesses the principles of quantum mechanics—including superposition, entanglement, and quantum tunneling—to process information in fundamentally new ways. While classical computers use bits that represent states of either 0 or 1, quantum computers use quantum bits, or qubits. Unlike classical bits, a qubit can exist in a superposition of the logical states 0 and 1 simultaneously. This property allows quantum-powered systems to perform certain complex computations much faster than classical computing systems. Quantum computing holds great potential to transform many sectors by enabling breakthroughs in quantum cryptography, information retrieval, optimization, and artificial intelligence. Through quantum algorithms such as Grover's and Shor's algorithms, quantum computers can significantly accelerate the speed of data searching and break encryption systems that would take classical computers billions of years to crack. While still in the relatively early stages of development, quantum computers hold considerable potential to shape our next generation of computing.

quantum computing qubits quantum information processing quantum algorithms Grover's algorithm Shor's algorithm quantum cryptography

Quantum computing is rapidly reaching a point of transition from a theoretical curiosity to a real-world, transformative technology. The advanced computational abilities of quantum-based systems, harnessed from the unique properties of quantum mechanics, promise to dramatically shift the speed and efficiency of our systems [1]. By moving beyond the classical computing paradigm of binary digits ("bits") that can only operate in two states (0 or 1) to qubits, which can exist in multiple states simultaneously through quantum superposition, quantum systems can solve certain computational problems much faster than classical machines [2]. This computational efficiency has wide-reaching implications for cybersecurity, information retrieval, and the optimization of artificial intelligence [3].

While quantum computing may be viewed as some distant and futuristic innovation more likely to be realized in the pages of a science fiction novel than in real-world applications, this technology already exists in some form through hardware like Google's Willow chip [4], IBM's superconducting quantum processors [5], IonQ's trapped ion systems [6], and software platforms such as Qiskit [7], Google's Cirq [8], and Microsoft's Quantum Development Kit (QDK) [9]. While today's quantum devices remain limited in scale and error rates, their continued evolution reflects rapid progress toward more robust and scalable systems [10]. These developments have far-reaching implications for fields such as cryptography [11], optimization [12], agri-food [13], and materials science [14]. If costs decline and demonstrable value is shown in real-world deployments, rapid adoption is plausible. In that case, the resulting

impact could be comparable to recent advances in generative artificial intelligence in late 2022/2023. A consolidated overview of the hardware platforms and software development kit (SDK) is provided in **Table 1**.

**Table 1.** Summary of Quantum Platforms and SDKs: Strengths, Limitations, and Maturity.

| Category | Platform | Type | Connectivity | Strengths | Limitations | Maturity |
|---|---|---|---|---|---|---|
| Hardware | Google Willow [4] | Superconducting (transmon) | Planar grid and nearest-neighbor | Fast gates; advanced calibration & benchmarking pipelines | Cryogenics; crosstalk; fidelity scaling | Research & Noisy intermediate-scale quantum computing (NISQ)-class flagship devices |
| Hardware | IBM Quantum [5] | Superconducting (transmon) | Coupling-map topologies (planar) | Cloud access; strong toolchain | Coherence & connectivity constraints typical of superconductors | Broad device family; leading NISQ access |
| Hardware | IonQ [6] | Trapped ions (hyperfine/optical) | All-to-all within a single chain | Long coherence; high single/two-qubit fidelities | Slower gates; scaling across chains needs photonic links | Commercial cloud systems; strong small to medium-circuit performance |
| Software | Qiskit [7] | SDK (Python) | IBM devices; providers for others; simulators | Rich transpiler; visualization; pulse-level access | IBM-centric by default | Actively maintained; wide community use |
| Software | Cirq [8] | SDK (Python) | Google devices and compatible simulators | Native abstractions; noise models; calibration workflows | Google-centric | Research & production tooling within Google ecosystem |
| Software | Microsoft QDK [9] | SDK (Q#, Python & C# interop) | Azure Quantum ecosystem; simulators; resource estimation | High-level Q# language; resource estimation; heterogeneous backend routing | Heavier tooling stack; best within Azure flow | Active tooling; growing backend support |

Given the impact that this quantum technology may have, it is critical to examine how organizations and society at large may anticipate opportunities and threats that will be presented and ensure that they are left in a favorable position for the decades to come.

This entry provides an introduction to quantum computing and explains related concepts within the context of their real-world impact on our systems for current and future professionals. The implications of these innovations for society are then discussed, including how they may impact various information systems, information retrieval, and the information, knowledge, and computing professionals. Through this analysis, the nature of quantum computing will be demystified, and the realistic disruptive potential of the technology will be highlighted.

## References


1. Barral, D.; Cardama, F.J.; Díaz-Camacho, G.; Faílde, D.; Llovo, I.F.; Mussa-Juane, M.; Vázquez-Pérez, J.; Villasuso, J.; Piñeiro, C.; Costas, N.; et al. Review of Distributed Quantum Computing: From single QPU to High Performance Quantum Computing. Comput. Sci. Rev. 2025, 57, 100747.
2. Steane, A.M. Efficient fault-tolerant quantum computing. Nature 1999, 399, 124–126.
3. Knill, E. Quantum computing. Nature 2010, 463, 441–443.
4. Lorenz, J.M.; Monz, T.; Eisert, J.; Reitzner, D.; Schopfer, F.; Barbaresco, F.; Kurowski, K.; van der Schoot, W.; Strohm, T.; Senellart, J.; et al. Systematic benchmarking of quantum computers: Status and recommendations. arXiv 2025, arXiv:2503.04905.
5. AbuGhanem, M. IBM quantum computers: Evolution, performance, and future directions. J. Supercomput. 2025, 81, 687.
6. Monroe, C.; Kim, J. Scaling the Ion Trap Quantum Processor. Science 2013, 339, 1164–1169.
7. Javadi-Abhari, A.; Treinish, M.; Krsulich, K.; Wood, C.J.; Lishman, J.; Gacon, J.; Martiel, S.; Nation, P.D.; Bishop, L.S.; Cross, A.W.; et al. Quantum computing with Qiskit. arXiv 2024, arXiv:2405.08810.
8. Cirq. Google Quantum AI. Available online: https://quantumai.google/cirq (accessed on 27 July 2025).
9. Mykhailova, M. Teaching Quantum Computing Using Microsoft Quantum Development Kit and Azure Quantum. In Proceedings of the 2023 IEEE International Conference on Quantum Computing and Engineering (QCE), Bellevue, WA, USA, 17–22 September 2023; pp. 15–20.
10. Ruane, J.; Kiesow, E.; Galatsanos, J.; Dukatz, C.; Blomquist, E.; Shukla, P. Quantum Index Report 2025. arXiv 2025, arXiv:2506.04259.
11. Vankayalapati, R.K. Harnessing Quantum Cloud Computing: Impacts on Cryptography, AI, and Pharmaceutical Innovation. Soc. Sci. Res. Netw. 2022, 5065730.
12. Montanaro, A. Quantum algorithms: An overview. NPJ Quantum Inf. 2016, 2, 15023.

13. Shahriar, S.; Corradini, M.G.; Sharif, S.; Moussa, M.; Dara, R. The role of generative artificial intelligence in digital agri-food. J. Agric. Food Res. 2025, 20, 101787.
14. de Leon, N.P.; Itoh, K.M.; Kim, D.; Mehta, K.K.; Northup, T.E.; Paik, H.; Palmer, B.S.; Samarth, N.; Sangtawesin, S.; Steuerman, D.W. Materials challenges and opportunities for quantum computing hardware. Science 2021, 372, eabb2823.

Retrieved from https://encyclopedia.pub/entry/history/show/131824