Quantum Physics: Fundamental Principles, Technologies, and Emerging Applications

Abstract

Quantum physics constitutes the foundational framework for understanding the behavior of matter and energy at microscopic scales, where classical physics fails. It introduces probabilistic laws, wave–particle duality, and nonlocal correlations that have revolutionized modern science. This survey reviews the fundamental principles of quantum physics, core phenomena such as superposition and entanglement, and explores emerging technologies including quantum computing, communication, sensing, and materials science.

Key Terms and Definitions

Quantum Physics: Study of matter and energy at atomic and subatomic scales.
Wave–Particle Duality: Dual behavior of quantum entities as both waves and particles.
Superposition: Ability of a quantum system to exist in multiple states simultaneously.
Entanglement: Strong quantum correlation between particles regardless of distance.
Qubit: Fundamental unit of quantum information.
Decoherence: Loss of quantum behavior due to environmental interaction.

Description

Quantum physics emerged in the early twentieth century to explain phenomena unexplained by classical mechanics. Key developments include the Schrödinger equation, the Heisenberg uncertainty principle, and quantum measurement theory. These principles form the basis of advanced technologies such as quantum computers, secure quantum communication systems, high-precision sensors, and novel quantum materials. Despite rapid progress, challenges such as decoherence, scalability, and error correction remain active areas of research.

Conclusion

Quantum physics has fundamentally transformed our understanding of nature and enabled revolutionary technologies. As experimental and theoretical research advances, quantum-based systems are expected to play a central role in future scientific discovery and technological innovation.

References

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