7. Majorana Particles – Science & Technology

Majorana particles are seen as a potential solution to the problem of decoherence in quantum computers, offering inherently stable and noise-resistant qubits.

Introduction to Majorana Particles

Definition - Majorana particles, or *Majorana fermions*, are hypothetical particles that are their own antiparticles.

Charge Property - Because they are self-antiparticles, they cannot carry an electric charge.

Origin - Proposed in 1937 by Italian physicist Ettore Majorana, who speculated on the possibility of such unique fermions within the framework of quantum field theory.

Experimental Status

No Fundamental Detection - To date, no fundamental Majorana particle has been conclusively discovered in nature.

Condensed Matter Physics - However, scientists have engineered quasiparticles in special superconducting materials that behave like Majorana fermions. These are known as Majorana zero modes.

Candidate in Particle Physics - Neutrinos are widely suspected of being possible Majorana particles, but this is yet to be experimentally confirmed.

Significance for Quantum Computing

Noise Resistance - Majorana modes allow quantum information to be stored *nonlocally*—the quantum state of a qubit is split between two separate locations. This makes them naturally resistant to local errors and disturbances, enhancing decoherence protection.

Scalability Advantage - If realized, Majorana-based qubits could simplify quantum computer architecture. This would allow more scalable systems capable of solving problems beyond the reach of current quantum computers.

Understanding Quasiparticles

Concept - A quasiparticle is a mathematical construct used to model how a group of interacting particles behaves collectively as if it were a single independent particle.

Not Real Particles - Quasiparticles do not exist as fundamental entities; they are emergent excitations in a medium.

Example - Ripples on water behave like "wave-particles," but they are just collective motion of water molecules.

Relevance - Majorana fermions observed in superconductors are not fundamental, but quasiparticles created through special interactions.

Fundamentals of Particle Classification

Two Broad Categories -

1. **Fermions** - Matter particles with half-integer spin (½, 3/2, etc.). Examples - electrons, protons, neutrons.
2. **Bosons** - Force carriers with integer spin (0, 1, 2, etc.). Examples - photons (electromagnetic force), gluons (strong force), W/Z bosons (weak force).

Types of Fermions -

1. **Dirac Fermions** - Fermions that are distinct from their antiparticles. Most known fermions (like electrons) are Dirac fermions.
2. **Majorana Fermions** - Fermions that are their own antiparticles. Still hypothetical at the fundamental level, though quasiparticle analogues exist.

Conclusion

Majorana particles represent one of the most fascinating possibilities in modern physics, sitting at the crossroads of particle physics and quantum technology. Their theoretical significance lies in explaining the true nature of neutrinos and matter-antimatter symmetry. Their practical significance lies in potentially providing a breakthrough in fault-tolerant quantum computing.

Source - https - //www.thehindu.com/sci-tech/science/how-majorana-particles-promise-to-shield-quantum-computers-from-noise/article70007626.ece