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ALTERNATIVE THINKING ABOUT INVESTMENTS

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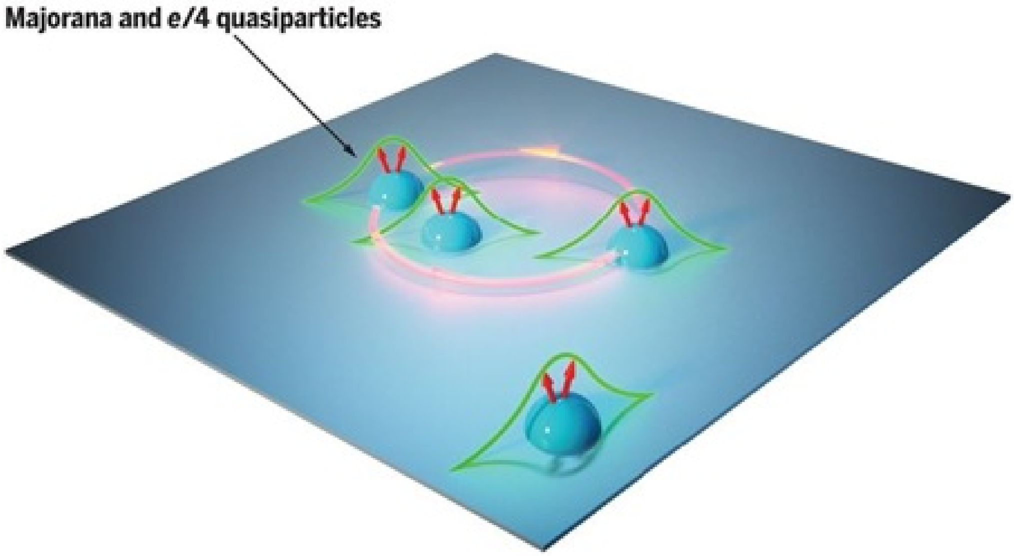
Microsoft's Majorana-1: Could it Redefine Particles, Matter, and the Future of Computing?



The Headline: Microsoft fabricated the Majorana-1, which leverages the field of topology and demonstrates data consistent with the existence of a Majorana state. Majorana fermions are exotic particles that resist environmental disturbances, which may allow quantum researchers to enhance stability and reduce decoherence. Unlike traditional qubits, its topological approach would store information in global properties, potentially bringing us closer to scalable quantum computing and practical real-world applications.

The Quantum Foundation (Let's Review Quantum Mechanics)

Quantum computing is built on the powerful principles of quantum mechanics, which govern the behavior of particles at infinitesimal scales. Unlike classical computers that use bits to represent 0 or 1, quantum computers leverage qubits, which can exist in multiple states simultaneously until it is measured due to superposition.[1] This unique property allows quantum computers to process vast amounts of data in parallel, giving them the potential to solve problems exponentially faster than classical systems.

A key principle of quantum mechanics is entanglement, where particles become linked, and their states are intertwined, no matter the distance between them.[2] This non-local property challenges classical understandings of reality. Similarly, wave-particle duality and quantization reveal that particles behave as particles and waves, with discrete energy levels, not continuous.[3,4] These fundamental principles set the stage for innovations in quantum computing, where qubits can represent complex states beyond the limitations of classical bits. For more fundamentals, read our *Mind-Bending Quantum Breakthroughs and Implications*.

Quantum computing is often hailed as the next frontier in computing technology. It promises transformative potential for pharmaceuticals, cybersecurity, and artificial intelligence by solving problems that current computers cannot. However, a critical obstacle to achieving quantum computing at scale is quantum decoherence (loss of quantum information), where qubits lose their quantum state due to interference from external noise, leading to errors. Achieving quantum fidelity—preserving a qubit’s quantum state long enough to perform calculations—is a massive hurdle. Traditional qubits, such as those in superconducting quantum computers, are easily disturbed by temperature fluctuations, electromagnetic interference, and other environmental noise, necessitating complex error correction to keep them stable.

Enter Topological Quantum Computing

In response to these challenges, *topological*[5] theory offers an approach to traditional quantum computing by using topological states of matter rather than traditional, more fragile ones. Topological states are collective states of the electrons in a material considered more resistant to noise, much like how two links in a chain can be shifted or rotated around each other while remaining a connected system (fault-tolerant).[6] At the heart of topological quantum computing research lies the use of Majorana Zero Modes (MZM), exotic quasiparticles that do not behave like fundamental particles, as you would expect of electrons and photons. Further, when appearing in condensed matter systems, they do not form traditional bulk matter like solids, liquids, or gases.[7,8] This contrarian behavior could allow information to be stored in a system's global properties rather than local changes, and these “rebels” would naturally resist environmental disturbances.[9] Majorana fermions were first theorized by Italian physicist Ettore Majorana in 1937 as a unique solution to the Dirac equation, which describes fundamental particles like electrons.[10]
In natural units, the Dirac equation is written as:[11]

$$(i\gamma_\mu\partial_\mu - m)\psi = 0$$

where:
- i is the imaginary unit
- γ_μ are the gamma matrices, which encode spin and relativity,
- ∂_μ represents spacetime derivatives,
- m is the mass of the particle,
- ψ is the Dirac spinor, representing the wave function of a fermion.

Why Is It Important?

The Dirac equation had key contributions in modern physics, including predicting antiparticles, discovering the positron, and essentially proving that every particle has a corresponding antimatter counterpart.[12] Unlike the Schrödinger equation, which is non-relativistic, the Dirac equation incorporates special relativity, making it applicable to particles moving near the speed of light.[13] It also naturally explains spin, predicting the intrinsic spin (+/-) ½ property of fermions, which is essential for understanding how electrons interact with magnetic fields.[14]

Majorana proposed that certain neutral particles could be their own antiparticles, unlike most fermions with distinct antiparticles (such as an electron and a positron).1[5] His idea remained purely theoretical for decades. However, in recent years, experimental data has suggested that unique quantum states resembling Majorana fermions can emerge in certain superconducting and topological materials.[16] These particles are now a focal point of quantum computing research due to their potential to create more stable and fault-tolerant states, meaning they could significantly reduce the likelihood of decoherence. The Majoranas themselves are considered non-Abelian[17] particles, meaning they are more immune to small environmental changes. This would allow the quantum information they carry to be "hidden" in a way that is far less prone to interference.

The Road to Scalable Quantum Systems

The realization of Majorana qubits could potentially benefit quantum computing due to their inherent noise resistance and the possibility of significantly reducing the number of physical qubits needed per logical qubit. This advantage stems from topological protection, which, as mentioned, theoretically minimizes error rates. Microsoft's Majorana 1 chip is a topological superconductor material made from carefully engineered combinations of indium arsenide and aluminum intended to manipulate Majorana fermions.[18] At this juncture, however, Majorana is more of a namesake, as Microsoft's paper did not demonstrate the existence of a Majorana qubit or definitively prove the existence of a Majorana state. The data presented was said to be consistent with a Majorana state, but significant technical hurdles remain before Majorana can be considered a viable approach to scalable quantum computing. Said milestones include demonstrating that Majorana could function as a qubit, implementing quantum logic operations, and scaling the system effectively.

Further, suppose the potential advantage of Majorana qubits lies in their promise of exceptionally low error rates, eliminating the need to fine-tune each qubit and reducing the number of qubits required for fault-tolerant quantum computing. In that case, these low error rates must be maintained in practice as the number of qubits is scaled. Currently, the benchmark for quantum computers to solve real-world, industrial-scale problems would require millions (or tens of millions) of qubits. Despite their theoretical promise, translating these advancements from the laboratory to commercial viability will require more innovation, as these systems need precise, sophisticated environments and highly specialized materials to keep the quantum state intact. For example, Microsoft's approach requires a mix of semiconducting and superconducting materials that must operate at milli-Kelvin temperatures (colder temperatures than space), requiring custom-built production methods.[19]

Current quantum systems do not yet run large-scale, real-world applications due to the challenges of adding more qubits without increasing error rates; however, Google's Willow announcement last quarter demonstrated, to a meaningful degree, that quantum error correction (QEC) can be scaled without necessarily increasing error rates, which supports theoretical predictions and boosts confidence in the industry.[20] Additionally, this does not mean that QEC is fully solved, as scaling to fault-tolerant, practical quantum computers remains a significant challenge. The success is encouraging but not universally applicable to all quantum architectures outside of superconducting. Microsoft's work with topological materials suggests a potential paradigm shift in that Majorana fermions may, or could, exist as quasiparticles in certain conditions, potentially enabling topologically protected qubits for fault-tolerant quantum computing and ultimately increasing the fidelity needed to rival classical supercomputers. In addition, we have had the privilege of assessing a cohort of leading quantum startups that, in conjunction with tech giants like Microsoft and Google, are making material contributions toward arranging and scaling qubits and building what could be the foundation of quantum computing hardware and software. As many subject matter experts have suggested, we may be on the cusp of meaningful quantum computing applications by the end of the decade instead of waiting decades.

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[1] https://scienceexchange.caltech.edu/topics/quantum-science-explained/quantum-superposition

[2] https://www.quantum-inspire.com/kbase/superposition-and-entanglement/

[3] https://www.thoughtco.com/wave-particle-duality-2699037

[4] https://www.sciencedirect.com/science/article/abs/pii/

[5] "Topology is the branch of mathematics concerned with the properties of a geometric object preserved under continuous deformations, such as stretching, twisting, crumpling, and bending; that is, without closing holes, opening holes, tearing, gluing, or passing through itself" source: (2021). *India: New state of the materials discovered that can lead to better, tunable, controllable quantum technologies. MENA Report.*

[6] https://www.nature.com/articles/d41586-025-00527-z#:~:text=Topological states are collective states,device made of indium arsenide.

[7] https://www.nature.com/articles/npjqi20151

[8] https://phys.org/news/2014-10-majorana-fermion-physicists-elusive-particle.html

[9] https://www.scientificamerican.com/article/exotic-paraparticles-that-defy-categorization-may-exist-in-many-dimensions/

[10] https://physics.mit.edu/news/first-sighting-of-mysterious-majorana-fermion-on-a-common-metal/

[11] https://www.hep.phy.cam.ac.uk/~lester/teaching/partIIIparticles/handouts2023/H2-without-appendices.pdf

[12] https://timeline.web.cern.ch/diracs-equation-predicts-antiparticles

[13] Ibid.

[14] https://www.scirp.org/journal/paperinformation?paperid=93205#:~:text=These particles are subject to,and odd have %C2%BD spin.

[15] https://news.stanford.edu/stories/2017/07/evidence-particle-antiparticle

[16] https://www.nature.com/articles/npjqi20151

[17] Non-Abelian particles are exotic quantum particles whose quantum states do not simply swap when exchanged but transform in a more complex way where their quantum state remembers the order in which they were moved. In standard physics, swapping two identical particles (like electrons) leads to either no change (bosons) or a sign change (fermions).

[18] https://news.microsoft.com/source/features/innovation/microsofts-majorana-1-chip-carves-new-path-for-quantum-computing/

[19] Ibid.

[20] https://blog.google/technology/research/google-willow-quantum-chip/

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