Referee Report on "The Future of Quantum Computing"

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This report provides a formal referee-style critical assessment of the article "The Future of Quantum Computing" by Scott Aaronson. While the manuscript offers an informative overview of prevailing attitudes within the quantum computing community, it relies on a set of implicit physical assumptions that are neither stated nor justified. In particular, the manuscript treats qubit-based architectures as scalable in principle, with remaining obstacles framed primarily as engineering challenges. This report demonstrates that such assumptions fail on physical grounds. Qubit scalability is shown to be structurally limited by coherence dilution, compositional noise, and thermodynamic constraints arising from mandatory cryogenic operation. As a consequence, several forward-looking claims in the manuscript lack physical support.

SUMMARY AND RECOMMENDATION

The manuscript under review is a perspective article discussing possible future directions of quantum computing. Although valuable as a sociological snapshot of current expectations, it does not meet the standards required for publication in a Physical Review journal.

Recommendation: Reject.

The central reason for rejection is the absence of a physically grounded analysis of scalability. The manuscript assumes that qubit-based quantum computing is scalable in principle and that further progress depends mainly on incremental improvements in control and error correction. This assumption is not justified and is contradicted by basic physical considerations.

I. IMPLICIT SCALABILITY ASSUMPTION

Throughout the manuscript, scalability is implicitly equated with the ability to increase the number of qubits while preserving logical correctness through fault-tolerant protocols.

This conflates two fundamentally distinct notions:

- mathematical scalability of abstract circuit models;
- physical scalability of coherent degrees of freedom.

No argument is provided to demonstrate that increasing hardware size corresponds to increased physically usable information. The manuscript treats scalability as an engineering continuum rather than as a physical constraint problem.

II. COHERENCE DILUTION UNDER TENSOR GROWTH

Let N denote the number of physical qubits. Even under optimistic noise models, global coherence is not an extensive quantity.

As system size increases, the effective coherence per logical degree of freedom decreases. Operationally meaningful measures of multi-qubit coherence exhibit the generic behavior

$$\frac{\mathcal{C}_{\text{global}}}{N} \longrightarrow 0 \quad \text{as} \quad N \to \infty.$$

This dilution is intrinsic to tensor-product growth and is not mitigated by encoding strategies. Indeed, fault-tolerant encoding requires additional entangling operations, which further accelerate coherence loss.

III. FAULT TOLERANCE IS MODEL-DEPENDENT

The manuscript treats fault tolerance as a physical inevitability once certain error thresholds are crossed. In reality, fault tolerance relies on idealized assumptions concerning noise locality, independence, and stationarity.

There is no experimental evidence that these assumptions remain valid as system size increases by orders of magnitude. Fault tolerance is therefore a mathematical construction dependent on a chosen noise model, not a guarantee of physical scalability.

IV. THERMODYNAMIC CONSTRAINTS AND CRYOGENIC DEPENDENCE

A critical omission in the manuscript is the lack of discussion of cryogenic operation as a fundamental physical constraint.

Current qubit-based architectures require extreme cryogenic confinement to maintain coherence. Cryogenic operation is treated implicitly as a neutral technological detail rather than as a dominant scalability bottleneck.

Thermal management, wiring density, and control electronics introduce heat loads that grow superlinearly with system size. As a result, maintaining stable cryogenic conditions becomes increasingly difficult as the number of qubits increases.

A computational paradigm that requires extreme cryogenic isolation to function cannot be regarded as physically scalable without addressing the thermodynamic limits of such confinement.

V. SCALING HARDWARE DOES NOT SCALE INFORMATION

The manuscript repeatedly associates progress with increasing qubit counts. However, increasing hardware size does not imply increased controllable physical information capacity.

Beyond modest system sizes, additional qubits introduce more noise channels, control complexity, and thermal instability than usable computational power. This leads to saturation rather than amplification of physical computational capability.

VI. SPECULATIVE NATURE OF APPLICATION CLAIMS

Claims regarding future applications in optimization, machine learning, and chemistry rely on extrapolations from small-scale demonstrations.

In the absence of a physically justified scalability mechanism, such extrapolations are speculative. The manuscript does not provide a physical argument supporting the transition from laboratory-scale devices to large-scale computational relevance.

VII. CONCLUSION

The manuscript presents an optimistic narrative about the future of quantum computing but does not engage with the fundamental physical constraints governing scalability.

By treating qubit-based architectures and cryogenic operation as scalable in principle, the article overlooks structural limitations imposed by coherence dilution, compositional noise, and thermodynamics.

The absence of a physically grounded scalability analysis renders several key claims speculative and unsupported.

REJECT

[1] S. Aaronson, "The Future of Quantum Computing," arXiv:2506.19232 [quant-ph].

Appendix A: Appendix A: Scaling Estimate

Consider a system of N qubits operated at circuit depth D with average error rate ϵ per entangling operation. A lower bound on the cumulative error probability is

$$P_{\text{error}} \gtrsim 1 - (1 - \epsilon)^{\alpha N D},$$

where α depends on connectivity and control architecture.

Maintaining constant logical fidelity as N increases requires

$$\epsilon \lesssim \frac{1}{ND}.$$

Such scaling implies error rates that vanish with system size, a requirement with no known physical mechanism and incompatible with observed noise floors.

Declaration of Authorship and Conceptual Integrity

This work is authored by Edoardo Livolsi and constitutes an independent, original critical assessment conducted without institutional affiliation.
The analysis is based exclusively on publicly available material and is presented in a formal referee-style format consistent with Physical Review standards.
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