ICFO

# Entanglement might enhance quantum battery power, but at a cost

## An international team of researchers has shown that the power boost quantum batteries gain from entanglement can come at the cost of reliability. The study, published in PRX Quantum, shows that future quantum batteries may need to simultaneously optimize speed, power and stability.

September 16, 2026

As modern technologies, and in particular microscopic quantum technologies, continue to advance towards miniaturization, they will increasingly need power sources that operate at those same tiny scales and within the quantum regime. In 2013, electrical batteries that operate under quantum principles, also known as **quantum batteries**, emerged as the perfect candidates for the job. Since then, researchers have explored (so far only in theory) how rapidly a quantum battery can be charged and how quantum effects, particularly many-body entanglement, can enhance this power.

Preliminary results suggest that, indeed, entanglement can make a difference. Yet, some months ago, a team of international researchers, including **Prof. Maciej Lewenstein at ICFO**,

started to ask themselves, ï¿½what if the enhanced power comes with great
r uncertainty?ï¿½. After all, at the core of our quantum reality there is uncertainty. We lea
ned that from Heisenberg a hundred years ago, when he derived his uncertainty relations, sta
ing that certain pairs of physical properties, such as position and momentum, canno
be simultaneously known with unlimited precision. We learned that these properties und
rgo quantum fluctuations, and that perfect accuracy is therefore unattaina
le. That question stayed with them, fueling their scientific curiosity. In the end, they discov
red that **a quantum battery cannot make both its work output and its power arbitrarily reliable at the same time**, a discovery that has now been published in PRX Quantum. ï¿½Th
s fundamental trade-off is the operational manifestation of quantum uncertainty in the conte
t of battery charging and discharging,ï¿½ says Dr. Tanmoy Pandit, research scientist at the
VTT Technical Research Centre of Finland who was involved in the st
dy. These results demonstrate that ï¿½**entanglement may certainly provide a power advantage, but it can also reduce how reliable that advantage is,ï¿½** says Dr. Nath Bera, researcher at the
Indian Institute of Science Education and Research (IISER) and senior author of the article.
This means that a battery may charge rapidly on average, while its instantaneous power
fluctuates substantially.
Hybrid protocols with balanced entanglement assistance may thus offer a better compromise
between speed and stability, the authors suggest. ï¿½Maximizing charging speed alone m
y not be sufficient,ï¿½ remarks Dr. Brij Mohan, researcher at University of Oulu and first au
hor of the article. ï¿½When building future quantum batteries, engineers may n
ed to simultaneously optimize stored work, charging power, fluctuations and reliabili
y.ï¿½ The team is now planning to investigate how these reliability limits behave un
er more realistic conditions. This means allowing quantum systems to interact wi
h their environments, so that they undergo decoherence, dissipation, control errors and i
perfect measurements. ï¿½Does environmental noise strengthen or weaken the work-power r
liability trade-off?ï¿½ asks Prof. Maciej Lewenstein to himself. ï¿½That is precisely the
next question we will try

**Reference:**

Mohan, B., Pandit, T., Lewenstein, M., Bera, M. N., Fundamental Limitations on the Reliabilities of Power and Work in Quantum Batteries, Phys, Rev. X Quantum, **7**, 033057 (2026).

**Acknowledgements:**

BM acknowledges funding by the Research Council of Finland by grant no 355824. TP acknowledges research funding from the QVLS-Q1 consortium, supported by the Volkswagen Foundation and the Ministry for Science and Culture of Lower Saxony and also the Research Council of Finland for funding through Grant No. 359284/Finnish Quantum Flagship. ML acknowledges support from: MCIN/AEI (PGC2018-0910.13039/501100011033, CEX2019-000910-S/10.13039/501100011033, Plan National STAMEENA PID2022-139099NB, project funded MCIN and by the ï¿½European Union NextGenerationEU/PRTRi ?½ (PRTR-C17.I1), FPI); Ministry for Digital Transformation and of Civil Service of the Spa ish Government through the QUANTUM ENIA project call - Quantum Spain project, and by the European Union through the Recovery, Transformation and Resilience Pl n - NextGenerationEU within the framework of the Digital Spain 2026 Age da; CEX2024-001490-S [MICIU/AEI/10.13039/501100011033]; Fundaci´o Cellex; Fun acio Mir-Puig; Generalitat de Catalunya (European Social Fund FEDER and CERCA pro ram; Barcelona Supercomputing Center MareNostrum (FI-2023-3-0024); Funded by the Eur pean Union (HORIZON-CL4-2022-QUANTUM-02-SGA, PASQuanS2.1, 101113690, EU Horizon 2020 FET-OPEN OPTOlogic, Grant No 899794, QUATTO, 101168628), EU Horizon Europe Pr gram (No 101080086 NeQSTGrant Agreement 101080086 - NeQST).