Observation of the Quantum Equivalence Principle for Matter-Waves

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Einstein's general theory of relativity is based on the principle of equivalence - in essence, dating back to Galileo - which asserts that, locally, the effect of a gravitational field is equivalent to that of an accelerating reference frame, so that the local gravitational field is eliminated in a freely falling frame. Einstein's theory enables this principle to extend to a global description of relativistic space-time, at the expense of allowing space-time to become curved, realising a consistent frame-independent description of nature at the classical level. Einstein's theory has been confirmed to great accuracy for astrophysical bodies. However, in the quantum domain the equivalence principle involves a gauge phase that is observable if the wavefunction - fundamental to quantum descriptions - allows an object to interfere with itself after being simultaneously at rest in two differently accelerating frames, one being the laboratory (Newtonian) frame and the other in the freely-falling (Einsteinian) frame. This is done with a novel cold-atom interferometer in which one wave packet stays static in the laboratory frame while the other is in free-fall. We follow the relative-phase evolution of the wave packets in the two frames, confirming the equivalence principle in the quantum domain. Our observation is yet another fundamental test of the interface between quantum theory and gravity. The new interferometer also opens the door for further probing of the latter interface, as well as to searches for new physics [1].

References

[1] O Dobkowski, B Trok, P Skakunenko *et al.*, arXiv:2502.14535 (2025)