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Gravitational Redshift, Equivalence Principle, and Matter Waves

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The gravitational redshift was the first consequence of General Relativity described by Einstein, and its measurement remains fundamental to our confidence in the theory. Clock comparison tests have reached an accuracy of 7×10^{-5}. We have performed redshift experiments based on matter waves, in which redshift anomalies modify material particles' Compton frequencies. These have reached an accuracy of 7×10^{-9}. For verifying the Einstein Equivalence Principle (EEP), these experiments are complemented by tests of Lorentz symmetry and universality of free fall (UFF). However, these tests are interrelated, as the proper time experienced by a clock or a matter wave is maximized on a geodesic, which relates the acceleration of free fall to the redshift. Here, we present a comprehensive framework for tests of the EEP, based on the Standard Model Extension. It shows that whether redshift measurements are related to measurements of UFF or not depends on the mechanism underlying the violation of the EEP, not on whether clocks or matter waves are used. Therefore, matter wave tests and clock comparisons are both valid measurements of the gravitational redshift and can probe violations of EEP that tests of UFF alone cannot probe. This framework also allows us to propose new tests of relativistic gravity: Searching for velocity- dependent effects and measuring force-free effects of gravity. Velocity-dependent effects of gravity are a consequence of nonlinear terms in the metric, which are proportional to $1/c^4$ that have never been measured in the laboratory but are responsible for the perihelion shift of mercury. Force-free effects of gravity are in analogy to the Aharonov-Bohm effect, in which a matter wave is phase-shifted by the existence of a potential even though there is no electric or magnetic field and, thus, no force.