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Ultracold Neutrons beyond Newton: Remarks on next-to-leading order effects

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In the recent years, ultracold neutrons have been used to explore the quantum nature of the gravitational interaction, like in the qBounce experiment. From a theoretical perspective, starting from Dirac equation in a curved spacetime, one can derive the non-relativistic Schr,"odinger equation that governs the evolution of the neutron's wave function in the Earth's gravitional field. This result has been obtained many times in literature, and at the lowest order it simply reproduce a Schrodinger system affected by a Newtonian potential. In this paper, we argue that, when going one step further in the perturbative expansion, one should be very careful, since terms that seems negligible at first glance, end up being of the same order of the other perturbative corrections to the neutron energy spectrum. Nevertheless, the current experiments' precision do not allow to probe for this corrections yet. Finally, we observe that, even if these contributions are negligible for the case of ultracold neutrons in Earth's gravity at the moment, they could still be relevant in other circumstances.

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