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Gravitational Optomechanics: Photon-Matter Entanglement via Graviton Exchange

The deflection of light in the gravitational field of the Sun is one of the most fundamental consequences for general relativity as well as one of its classical tests first performed by Eddington a century ago. However, despite its center stage role in modern physics, no experiment has tested it in an ostensibly quantum regime where both matter and light exhibit non-classical features. This paper shows that the interaction which gives rise to the light-bending also induces photon-matter entanglement as long as gravity and matter are treated at par with quantum mechanics. The quantum light-bending interaction within the framework of perturbative quantum gravity highlights this point by showing that the entangled states can be generated already with coherent states of light and matter exploiting the non-linear coupling induced by graviton exchange. Furthermore, the quantum light-bending interaction is capable of discerning between the spin-2 and spin-0 gravitons thus also providing a test for alternative theories of gravity at short distances and at the quantum level. We will conclude by estimating the order of magnitude of the entanglement generated by employing the linear entropy. In particular, we find that a half-ring cavity of radius 0.25 m placed around a 10 kg mechanical oscillator operating at 150 Hz, could be used to generate linear entropy of order unity using a petawatt laser source at optical wavelengths. While the proposed scheme is beyond the current experimental realities it nonetheless initiates the discussion about testing the spin of the gravitational interaction at the quantum level.

Secondary track

T15 - Quantum technologies in HEP (special topic 2025)

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