Universality of gauge coupling constant in the Einstein-QED system

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Introduction

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Although the Standard Model of particle physics is very successful in describing most of the fundamental interactions, it does not describe quantum gravity.

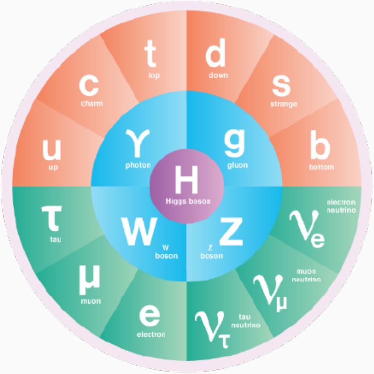

Figura 1: Particles of the SM

- A full theory of quantum gravity is nonrenormalizable;[1]
- However, we can treat gravity as an effective field theory.[2,3]

$$g_{\mu\nu} = \eta_{\mu\nu} + \kappa h_{\mu\nu}. \tag{1}$$

We also need to introduce higher derivatives terms in the action to take care of the divergences proportional to higher order in momentum coming from the gravitational interaction.

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[3] C. P. Burgess, Living. Rev. Rel. **7**, 5 (2004).

On the running of the coupling constants

Using this framework, it is possible to study the running of the coupling constants.[4,5,6] However, as pointed by Anber, Donoghue and El-Houssieny[7], this treatment for quantum gravity may lead to inconsistencies, such as non-universality of the coupling constants or different results depending on the mathematical approach used to do the computations.

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[7] M. M. Anber, J. F. Donoghue and M. El-Houssieny, Phys. Rev. D **83**, 124003 (2011) doi:10.1103/PhysRevD.83.124003 [arXiv:1011.3229 [hep-th]].

Model and results

Model

We are working with the Einstein-QED model with two particles with different masses,

$$\mathcal{L} = \sqrt{-g}\sum_{l}\Big\{\frac{2}{\kappa^2}R - \frac{1}{4}g^{\mu\nu}g^{\alpha\beta}F_{\mu\nu}F_{\alpha\beta} + i\bar{\psi}_l(\nabla_\mu - ieA_\mu)\gamma^\mu\psi_l - m_l\bar{\psi}_l\psi_l + \mathcal{L}_{HO} + \mathcal{L}_{GF} + \mathcal{L}_{CT}\Big\}, \quad (2)$$

where,

$$\mathcal{L}_{HO} = i\bar{\psi}_l \,\Box\left(\tilde{e}_1\not{\partial} - \tilde{e}_2 m_l\right)\psi_l - \frac{\tilde{e}_3}{4}F^{\mu\nu}\Box F_{\mu\nu} + \frac{i\tilde{e}_4}{2}\bar{\psi}_l\gamma_\mu\partial_\nu\psi_l F^{\mu\nu} + \cdots . \quad (3)$$

And we define the renormalized gauge coupling constant as,

$$e = \mu^{-2\epsilon}\frac{Z_2 Z_3^{1/2}}{Z_1}e_0. \quad (4)$$

Results

Using the Ward-Takeshi identity, we write $Z_2 = Z_1$ and need only to compute the photon self-energy to find the renormalized coupling constant.

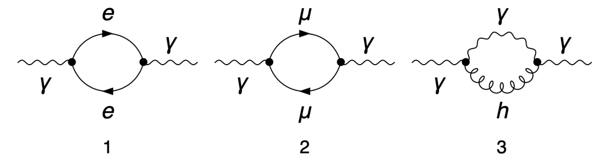

Figura 2: Feynman diagrams for the photon self-energy.

And we obtain,

$$Z_3 = -\frac{e^2}{6\pi^2\epsilon} + f_3(m_l, e, \kappa), \tag{5}$$

at one-loop order.

From (5), we can see that at one-loop order there is no contribution to the renormalization of the gauge coupling constant. Therefore, it is universal as in the usual QED.

It is important to notice that our result is different from some results obtained using the effective action methods, where it was found that there may be gravitational corrections at one-loop order.[8] However, their resuts are gauge dependent and therefore non-physical. Then, their results and ours are qualitatively equivalent.

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[8] J. C. C. Felipe, L. C. T. Brito, M. Sampaio and M. C. Nemes, Phys. Lett. B 700, 86 (2011) [arXiv:1103.5824 [hep-th]].; J. C. C. Felipe, L. A. Cabral, L. C. T. Brito, M. Sampaio and M. C. Nemes, Mod. Phys. Lett. A 28, 1350078 (2013). [arXiv:1205.6779 [hep-th]].

Conclusions

Conclusions

- In this work, we computed the renormalized gauge coupling constant of the Einstein-QED system and found that it is universal and does not receive gravitational corrections at one-loop order
- We also did the same computation using scattering processes and found the same results. This will be available soon in a new version of our work.
- Finally, we noticed that our results differ from the previous ones in the literature using the effective action method, but their results are gauge dependent, therefore non-physical.

Acknowledgement

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