Analogy between graphene light-matter interactions and strong field quantum electrodynamics

D. Gagnon, F. Fillion-Gourdeau, J. Dumont, C. Lefebvre, and S. MacLean
Université du Québec, INRS-Énergie, Matériaux et Télécommunications, Varennes, Québec, Canada
Institute for Quantum Computing, University of Waterloo, Waterloo, Ontario, Canada
denis.gagnon@emt.inrs.ca

Abstract. We theoretically describe the use of graphene as a "QED simulator" following the formal analogy between quantum electrodynamics (QED) and the dynamics of low-energy excitations in graphene [1]. More specifically, time-dependent electron-hole pair production in graphene can be used to simulate QED pair production from vacuum either in the multiphoton or Schwinger regime (also known as tunneling regime). We concentrate on the case where the system is driven out of equilibrium by the application of a linearly polarized or circularly polarized laser excitation. For applied fields of magnitude $E_0 = 10^7$ V/m, the multiphoton regime corresponds to optical frequencies and the tunneling regime corresponds to terahertz frequencies. The resulting electron momentum densities are computed via a split-operator method for the numerical solution of the time-dependent Dirac equation [2]. For a linearly polarized excitation and a single optical cycle applied on the graphene sample, our results can be intuitively explained in terms of Landau-Zener-Stueckelberg interferometry and the Kibble-Zurek mechanism [3]. This highlights the unparalleled contribution of this 2D material to fundamental physics studies. Graphene in a strong magnetic field is also discussed in the context of electron-hole pair creation [4].

References

[1] V. Gusynin, S. Sharapov, and J. Carbotte, "AC conductivity of graphene: from tight-binding model to 2+1-dimensional quantum electrodynamics," *Int. J. Mod. Phys. B*, vol. 21, no. 27, pp. 4611–4658, 2007.

[2] F. Fillion-Gourdeau and S. MacLean, "Time-dependent pair creation and the Schwinger mechanism in graphene," *Phys. Rev. B*, vol. 92, p. 035401, 2015.

[3] F. Fillion-Gourdeau, D. Gagnon, C. Lefebvre, and S. MacLean, "To be submitted." 2016.

[4] D. Gagnon, F. Fillion-Gourdeau, J. Dumont, C. Lefebvre, and S. MacLean, "Driven quantum tunneling and pair creation with graphene Landau levels," *Phys. Rev. B*, vol. 93, no. 20, p. 205415, 2016.