The Free Electron Gas in Cavity QED

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In this work we study the free electron gas model [1] in cavity QED. Firstly, we consider the free electron gas coupled to a single quantized mode of a cavity. In the single mode case this many-body system is exactly solvable, and we provide the full solution in the thermodynamic limit. Furthermore, we prove that if the diamagnetic A^2 term [2, 3] is neglected the system becomes unstable and no ground state exists for the electron gas coupled to the cavity. By performing linear response [4] in both the electronic and the photonic sector of the theory, we give a fully microscopic, quantum electrodynamical description of plasmon-polariton excitations, which in the limit of no cavity recovers the plasmon excitations and the dielectric function given by Drude's theory. Then, out of the single mode theory we construct an effective field theory of infinitely many modes in the continuum. For the effective theory we define rigorously the effective coupling and the ultraviolet behavior of the theory, and we compute the Casimir force between the mirrors of the cavity due to the zero-point energy. Depending on the ultraviolet cutoff, the Casimir force can be either attractive or repulsive. Lastly, we perform linear response in the effective theory and we obtain from first principles, and without introducing an artificial broadening, an asymmetric Lorentzian shape for the response functions, from which we can deduce lifetimes of the excitations.

References

[1] A. Sommerfeld. Zur elektronentheorie der metalle auf grund der fermischen statistik. 47(1), January 1928.

[2] Vasil Rokaj et al. *Phys. Rev. Lett.*, 123:047202, Jul 2019.

[3] Schäfer et al. *arXiv:1911.08427 [quant-ph]*, 2019.

[4] Johannes Flick et al. *ACS Photonics, 6, 11*, 2019.