Contribution of polaritonic modes to the zero-temperature Casimir interaction between two graphene sheets

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Introduction

Our setup consists of two parallel sheets of graphene at zero chemical potential placed in vacuum and separated by a distance L. The system is at zero temperature. We describe the optical response of graphene within the Dirac model from which we obtain the reflection coefficients

$$r_{\mathrm{TM}}(\omega, k) = \frac{\kappa \Pi_{00}}{\kappa \Pi_{00} + 2k^2}, \tag{1a}$$

$$r_{\mathrm{TE}}(\omega, k) = \frac{k^2 \Pi_{\mathrm{tr}} - \kappa^2 \Pi_{00}}{k^2 (\Pi_{\mathrm{tr}} + 2\kappa) - \kappa^2 \Pi_{00}}, \tag{1b}$$

where $k = \sqrt{k_x^2 + k_y^2}$, $\kappa = \sqrt{c^2k^2 - \omega^2}$ and Π is the polarization tensor [1]. Furthermore, we assume that the graphenes band structure features a gap $\Delta \approx 2 - 20\mathrm{meV}$, which could happen, e.g. if a layer is placed on a specific substrate.

Casimir Energy

The Casimir energy can be calculated as a sum over modes [2]

$$E_{Cas} = \left[\sum_{\sigma,k,n} \frac{\hbar \omega_n^\sigma(k)}{2} \right]_{L\to\infty}^{L}, \tag{2}$$

where the brackets indicate that one has to substract the value of the sum for infinite distance from its values calculated for finite separations. The behaviour of the Casimir energy as a function of the distance between the graphene sheets is represented below.

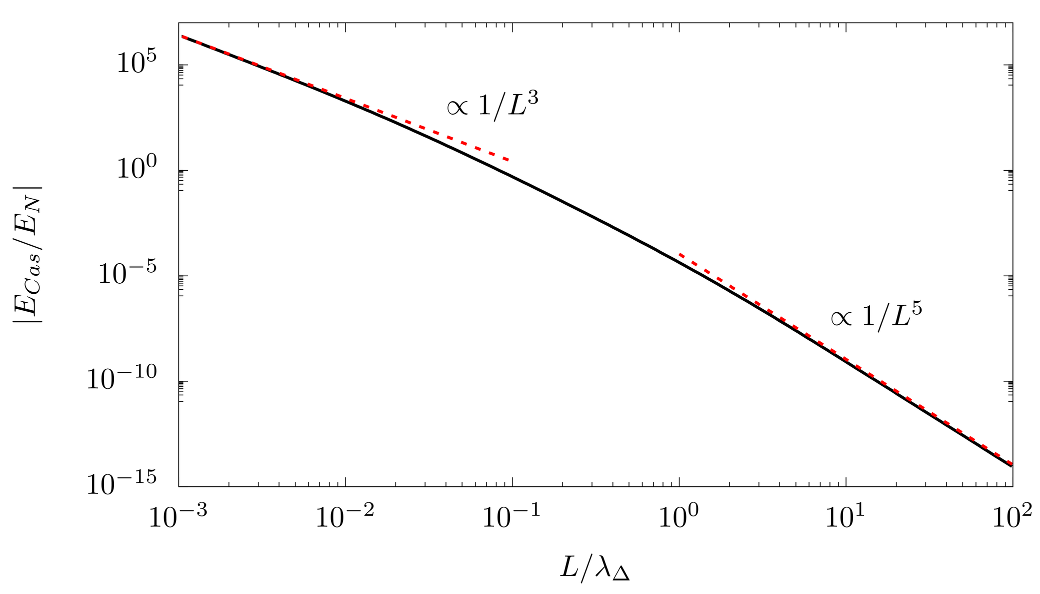

Figure 1: Casimir energy as a function of the separation between the graphene layers. We observe a change in power law for separations $L \approx \lambda_\Delta$.

The intrinsic length scale of the system is given by $\lambda_\Delta = \frac{\hbar c}{2\Delta} = 1/k_\Delta$ and $E_N = \frac{\hbar c k_\Delta^3 A}{4\pi}$. The Casimir energy in graphene follows the same scaling as in the ideal mirror case only for very small separations, albeit being much smaller in magnitude. At separations larger than λ_Δ it scales like $1/L^5$ showing that the presence of a band gap reduces the strength of the Casimir interaction.

Polaritonic Modes

Each graphene layer features a surface polariton $\omega_0(k)$. This matter-light state is associated with an evanescent field in vacuum. If the sheets are brought closely together their polaritons interact, giving rise to an antisymmetric mode $\omega_+(k)$, which induces repulsion between the layers, and to a symmetric mode $\omega_-(k)$, which induces attraction [3].

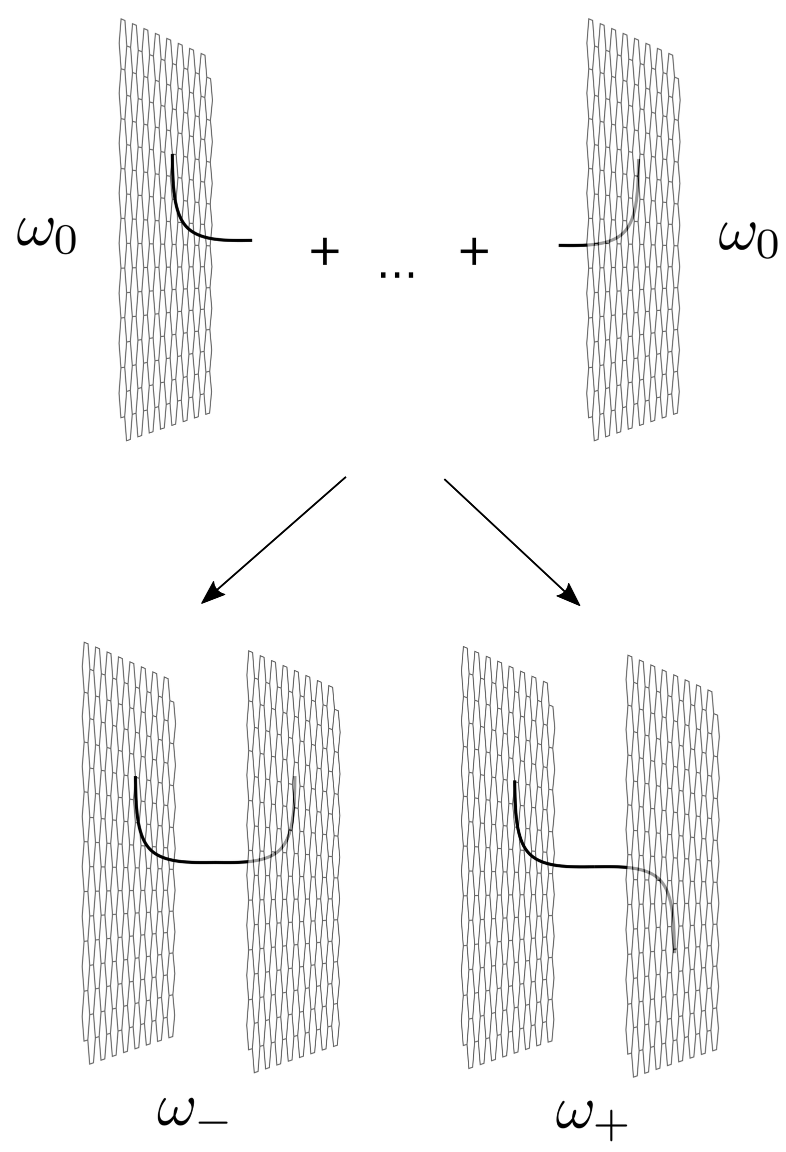

Figure 2: The polaritons of the individual sheets couple if brought together producing an antisymmetric and symmetric mode.

Mathematically the isolated and the coupled surface polariton modes are described by the solutions of

$$\frac{1}{r} = 0 \quad \text{or} \quad 1 \pm r e^{-\kappa L} = 0, \tag{3}$$

respectively, where r is the reflection coefficient.

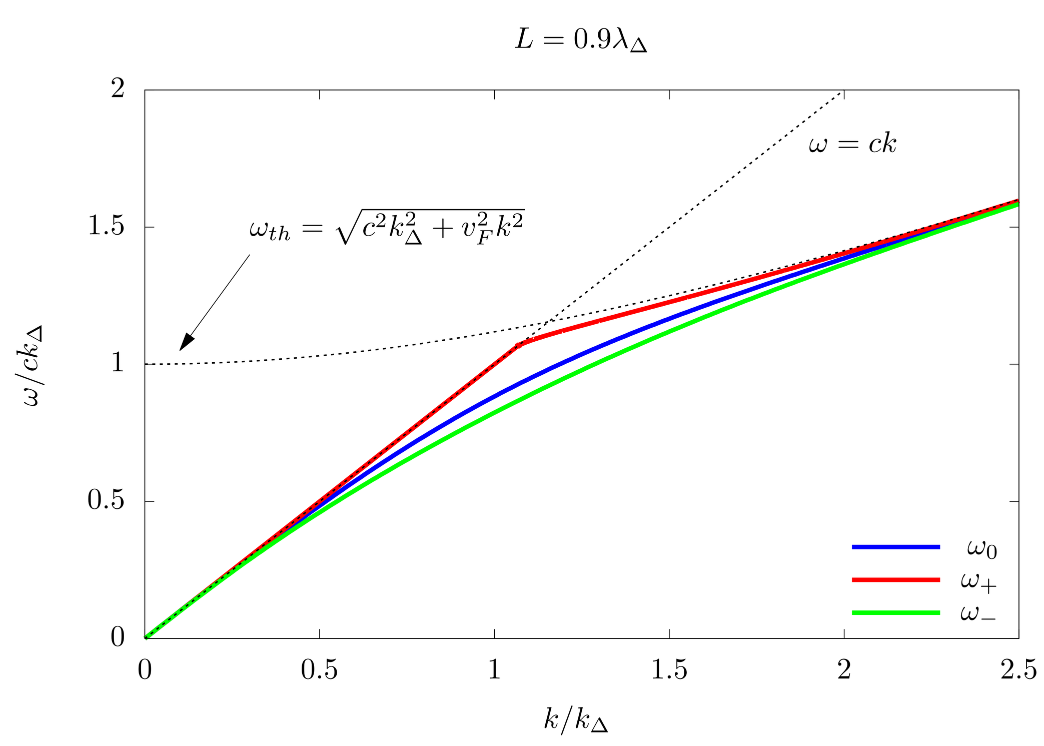

Figure 3: Dispersion relation of the polaritonic modes for $\alpha = v = 1/2$ for better visibility. Dotted lines show the different regimes.

For our system (zero chemical potential), there only exist polaritonic modes associated with a TE-polarized electromagnetic fields. Our analysis shows that also the coupled modes are always associated with an evanescent field.

Contribution

The polaritonic contribution to the Casimir energy is obtained by restricting the sum of Eq. (2) only to the polaritonic modes [4]

$$E_{pl} = E_N \int_0^\infty [\omega_+ + \omega_- - 2\omega_0]\, k\mathrm{d}k. \tag{4}$$

We see that up to a maximum at $L \approx 74\lambda_\Delta$ this energy has a positive slope, indicating that the polaritons give rise to an attractive contribution to the total force. Beyond the maximum the slope is negative, revealing that the polaritons generate a repulsive force.

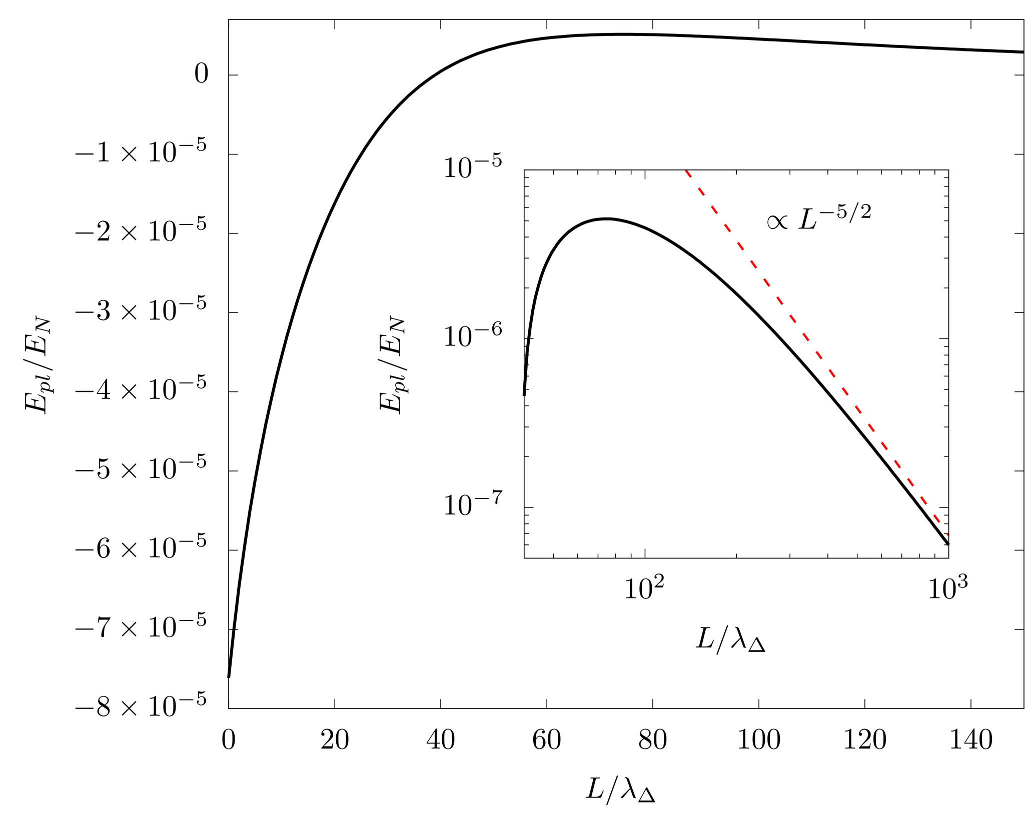

Figure 4: Contribution of polaritons as a function of the separation between the graphene layers. Inset: Asymptotic behaviour at large separation.

Contrary to results obtained with classical material models, E_{pl} actually approaches a constant as $L \to 0$ [4]. This means that, for our system, the zero-temperature Casimir interaction is dominated at short separation by propagating modes.

References

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