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Intraband collective excitations in a two-dimensional electron gas with Dirac spectrum

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The polarizability of two-dimensional electrons with the Dirac spectrum shows a set of peculiarities as function of the frequency, ω, and the wavevector, k; among these – a divergence and branching at $\omega \to \pm v_F k$, where v_F is Fermi velocity. We have used the semiclassical approach to define the polarizability function in the complex ω-plane and to obtain transparent results on the dynamics of collective excitations. By solving the initial value problem for the system of Boltzmann-Vlasov and Poisson equations with different forms of initial disturbances of the distribution function and charge, we found that collective excitations of the electrons with the Dirac spectrum are composed by a few distinct components of the oscillations. Among these, there are always well known *sustained plasmon oscillations* with dispersion $\omega \propto \sqrt{k}$ in long-wavelength limit. Also, there exist *new type of oscillations* with the carrier frequency $\omega = v_F k$; they are of a transient character, decaying in time according to a *power law*. Mathematically, the latter component of the oscillations arises due to the branching feature of the polarizability function. Finally, a strongly anisotropic initial disturbance of the electron distribution generates *another component of undamped oscillations* with frequency $\omega = v_F k \cos\alpha_0$, where α_0 being the angle between the wavevector k and the anisotropy direction. We interpreted these oscillations as van Kampen's modes in the plasma of the Dirac electrons.

The results obtained demonstrate that the semiclassical approach is adequate to describe the real-space dynamics of collective excitations in the Dirac electron gas, including graphene and graphene-polar substrate systems. We suggest that our predictions can be verified by infrared pump-probe nanoscopy [1] or by time-resolved electrical measurements [2].

1. *M. Wagner et al.*, Ultrafast and nanoscale plasmonic phenomena in exfoliated graphene revealed by infrared pump–probe // Nanoscopy Nano Lett.-2014.-**2.**-P. 894-900.
2. *N. Kumada, et al.*, Plasmon transport in graphene investigated by time-resolved electrical measurements // Nature Comm.-2013.-**4**.-P. 1363-1368.