Moment Sum Rules for a Layered Electron Gas.

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(ricevuto il 24 Febbraio 1987)

Summary. — We have evaluated the first few frequency moments of the dissipation spectra for longitudinal and transverse excitations in a layered electron gas model, consisting of a periodic stack of two-dimensional electron gases. Short-range interplanar correlations yield a specific contribution to the first moment of the current-current dissipation spectra whenever the wave vector has a finite perpendicular component. The result is interpreted as evidence for additional excitations lying above the well-known acoustic plasmon in this model system.

PACS. 71.45. – Collective effects.

1. – Introduction.

A layered electron gas, consisting of a periodic stack of planes inside which the electrons are constrained to move, was first considered by Visscher and Falicov (') as a model for dielectric screening in graphite intercalates. The same model has subsequently found numerous applications in connection with semiconductor superlattices.

The plasma excitation frequency of the layered electron gas (LEG) model, as

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evaluated\(^{(2-5)}\) in the random phase approximation (RPA), shows a very remarkable behaviour as a function of the in-plane and perpendicular components of the wave vector \((q \text{ and } k, \text{ say})\). At low \(q\), in particular, the plasma frequency takes the usual 3D value for \(k = 0\), but has a linear dispersion as a function of \(q\) for \(k \neq 0\). The latter behaviour has been demonstrated experimentally by inelastic light scattering from GaAs-(AlGa)As heterostructures\(^{(6)}\).

Theoretical work on the 3D electron gas has shown that useful information on the dispersion relation of the plasma excitation at long wavelengths can be deduced from a calculation of the third spectral moment of the density-density response function\(^{(7-12)}\). We consider in this paper a similar evaluation for the LEG, together with that of the analogous sum rule for the transverse current response function. As we shall see, our results, for the case \(k = 0\), parallel the known 3D results, except for trivial changes which are due to the reduced dimensionality of the dynamics of the electrons and lead in the appropriate limit to the moment sum rules for a 2D system. In the case \(k \neq 0\), on the other hand, the RPA plasmon does not suffice to fulfil the third-moment sum rule even to leading order, when multipolar couplings between electrons in different planes in the periodic model system are allowed. We interpret this result as evidence for the existence of higher-lying excitations associated with interplanar interactions.

2. – Some general definitions.

The LEG is described by the Hamiltonian (see appendix)

\[
H = \sum_x \varepsilon_x c_x^\dagger c_x + \frac{1}{2} \sum_x \sum_{\alpha, \beta} v_{\alpha}(\alpha) \sum_x c_x^\dagger c_x'^\alpha c_{x' + x}^{\alpha\beta} c_{x' - x},
\]

where \(\varepsilon_x = q^2/2m\) and

\[
v_{\alpha}(\alpha) = \sum_{\alpha} v(q, k + G) = \frac{4\pi d_{\alpha}^2}{q} \frac{\sinh(qd)}{\cosh(qd) - \cos(kd)}.
\]