ROTOPLASMONIC EXCITATIONS IN THE ELECTRON GAS

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By means of group theory we show that collective excitations of the electron gas which carry certain angular momentum in addition to the linear momentum exist. The energy $E^m_q$ of such excitations has been calculated. For $q$ tending to zero $E^m_q$ goes to $E^0_q$, i.e. it coincides with the usual plasmon energy.

Hitherto many types of electronic excitations have been observed in solids. Such are e.g. particle-hole pairs, plasmons, excitons, electronic polarons.

In this paper we shall show theoretically that other types of excitations exist and calculate the excitation spectrum of a type of such excitations, which will be named "rotoplasmonic excitations" as their excitation spectrum is similar to that of plasmons for small $q$ and carry certain angular momentum in addition to the linear momentum $q$.

The many electron Hamiltonian in the jellium model approximation (in the second quantization formalism) is

$$
\hat{H} = \sum_{k} \frac{\gamma}{2} \frac{k^2}{2} a_k^{+} a_k + \sum_{q} \frac{2\pi}{2} \rho_q^+ \rho_q - \sum_{q} \frac{2\pi}{2} \rho_0^+ \rho_0
$$

(1)

where the prime at the summation means that the term in $q = 0$ is not included; this is because the positive background cancels this term. By $a_k^+$, $a_k^-$ we denote the well-known creation and annihilation operators, respectively, in the $\vec{k}$ representation.

J. T. Devreese et al. (eds.), Recent Developments in Condensed Matter Physics
The operator $\rho_q^+$ is
\[ \rho_q^+ = \sum_k a_{k+q}^+ a_k^+ . \]

This Hamiltonian is invariant under the full space group $I_3^3$ in the three dimensional space which included all translations and rotations. Up to now only the translation group has been taken into account. This gave rise to excitations characterized by the irreducible representations of this group. However, the irreducible representations of the symmetry group of the jellium Hamiltonian, $I_3^3$, are labelled by two quantum numbers $m$ and $|q|$, where $m$ is the eigenvalue of the component of the angular momentum about the $q$ direction, and $q$ is the linear momentum. Thus the wavefunction which transforms according to the irreducible representations of $I_3^3$ are labelled as $|\psi_q|^m$. The eigenstates of the Hamiltonian belonging to the irreducible subspace $|\psi_q|^m$ have the same energy irrespective of the direction of $q$.

The study of these representations is simplified when one uses the algebra of the generators of the group, where one can use the Casimir operators for characterizing the irreducible representations.

In order to derive the rotoplasmonic states and the corresponding excitation energies, we follow a procedure similar to that of Pines in his derivation of the plasmon excitations. It must be noted that this is different from the one that Bohm and Pines developed initially for the R.P.A.

In this derivation one makes use of the approximate relation,
\[ [H, a_k^+ \rightarrow a_k^+] \approx (\frac{2}{2} + \hat{q} \hat{k}) a_k^+ a_{k+q}^+ + \frac{4\pi}{2q} (n_k - n_{k+q}) \rho_q^+ \]

where $n_k$ is the Fermi distribution function at $T = 0$ and constructs an operator $b_q^+$ of the form
\[ b_q^+ = \sum_k f(k) a_{k+q}^+ a_k^+ \]

by the requirement
\[ [\hat{H}, b_q^+] = \omega b_q^+ \]
where $\omega$ is to be calculated. Because of the relations (2), (3), (4) it is possible to expand $f(k)$ in a series of the form