3 Electronic Elementary Excitations

In inelastic light scattering experiments on semiconductor nanostructures, electronic excitations are created or annihilated in the low–dimensional electron systems under investigation. Thus, the main body of this book will deal with the physics of those electronic elementary excitations in various systems and under various conditions. Before we elaborate on the basic concepts of the inelastic light scattering processes themselves in the following chapter, the electronic elementary excitations shall be introduced and discussed here. We will do this by the – most prominent – example of the excitations of Q2D electron systems, realized in modulation–doped GaAs–$Al_xGa_{1-x}As$ quantum wells. These excitations can be categorized into so called spin–density excitations (SDE) and charge–density excitations(CDE), which both are collective plasma oscillations of the Q2D system, and, single–particle excitations (SPE). In particular, the observation of intersubband SPE [1] – which are thought to be electronic excitations, which are not affected by the Coulomb interaction – has posed a puzzle, and has been controversially discussed. We will come to this discussion at various places later in this book, when considering the resonant scattering in quantum wells and in quantum dots. In particular in Chap. 5 we will see that – at least for quantum dots – the SPE's are actually *collective* excitations: SDE's and CDE's. However, the many–particle interaction effects partly cancel under specific conditions so that the energies are close to single–particle energies of a noninteracting system. Historically, in 1979, intersubband CDE and SDE in GaAs–AlGaAs quantum wells [2] and heterojunctions [3] were the first electronic excitations, which were observed in semiconductor nanostructures by inelastic light scattering by A. Pinczuk et al. and G. Abstreiter et al., respectively.

It shall be noted here that the excitation categories, which will be described in this section for Q2D systems, can be transferred to systems with lower dimensionality, i.e., quantum wires and quantum dots. The specialities of those systems will be introduced and discussed in the respective following chapters. Furthermore, we will in the current section already make use of polarization selection rules for the electronic excitations, and of the fact that in inelastic light scattering experiments a finite quasi momentum $\boldsymbol{q}$ can be transferred to the excitations. These characteristic features of the inelastic light scattering process itself will be introduced in detail later, in Chap. 4.

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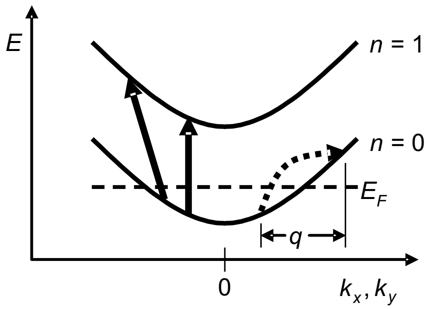

Fig. 3.1. Schematic picture of intersubband and intrasubband single–particle transitions in a Q2D electron system. The label k_x, k_y at the x axis shall indicate that for a Q2D system the dispersion of a subband is not a one–dimensional parabola but rather a paraboloid in k_x and k_y directions

3.1 Single–Particle Continua

We will start the discussion of elementary electronic excitations by considering a Q2D electron system with two subbands, where only the lowest subband is occupied by electrons up to the Fermi energy E_F at temperature $T = 0$ K, as displayed in Fig. 3.1. For the moment, the Coulomb interaction shall be neglected, and the electrons are considered to be independent particles. In this single–particle picture, we can think of *intersubband* and *intrasubband* SPE, as indicated in Fig. 3.1 by thick solid and dotted arrows, respectively. In the following – and for the rest of this book – we will always denote a quasimomentum or wave vector, which is connected to an electronic excitation, by $\boldsymbol{q}$, while the quasimomentum of an electron in the ground state will be labeled by $\boldsymbol{k}$ (for a Q2D system $\boldsymbol{k} \equiv \boldsymbol{k}_{||} = (k_x, k_y)$). In Fig. 3.1 we can see that concerning intersubband excitations we can imagine transitions with finite wave–vector transfer q, and vertical transitions with $q = 0$. Intrasubband SPE, on the other hand, have nonzero energies for $q \neq 0$, only. All possible SPE, in dependence on the wave vector q, form the *single–particle continua.* Figure 3.2 displays schematically the intra– and intersubband single–particle continuum for the above introduced two subband system. The insets illustrate some selected situations at the edges of the continua. The upper edge of the intrasubband continuum is given by

$$E(k_F + q) - E(k_F) = \frac{\hbar^2 (k_F + q)^2}{2m^*} - \frac{\hbar^2 k_F^2}{2m^*} = \frac{q k_F}{m^*} + \frac{\hbar^2 q^2}{2m^*} \sim \frac{q k_F}{m^*} , \quad (3.1)$$

if $k_F \gg q$, i.e., the Fermi wave vector, k_F, is large compared to the wave vector, q, of the excitation. The lower bound of the continuum is given by zero for all $q < 2k_F$, since the 2D subband is a paraboloid, and so an intrasubband transition can start directly at the Fermi energy and end at an infinitesimally small energy just above the Fermi energy at a different point of the paraboloid