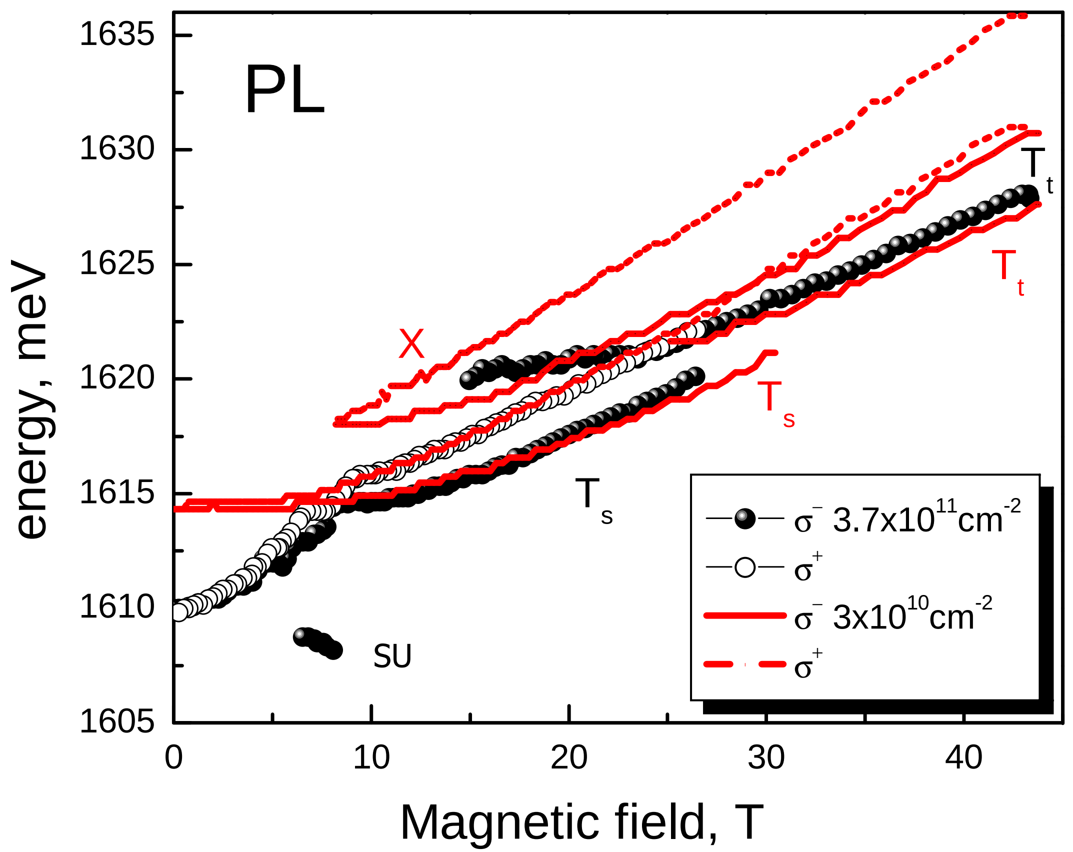
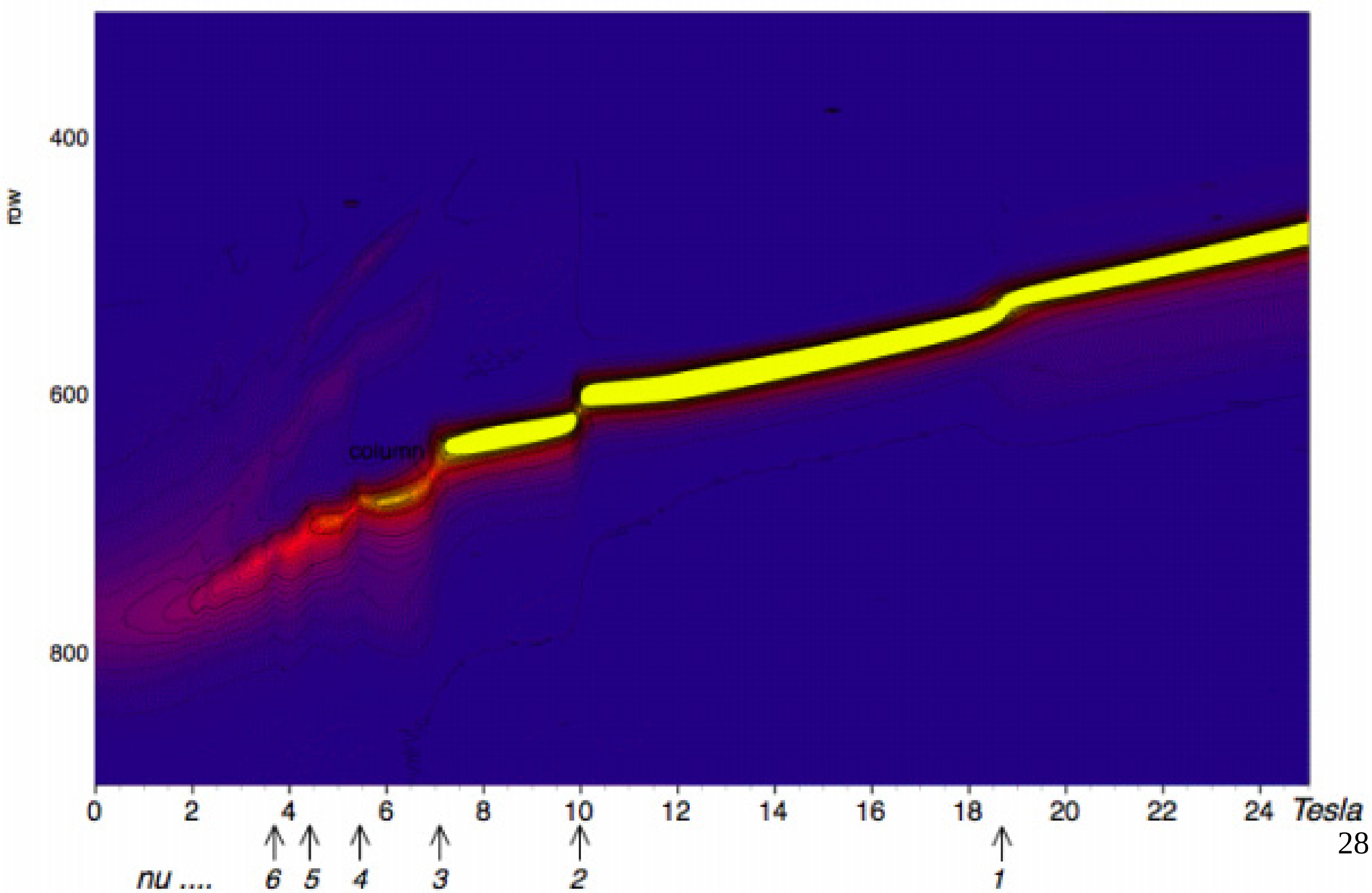
In heavily doped QW in zero magnetic fields the PL line is shifted to the low energies from its position in low doped structure. The value of this shift is of the order of Fermi energy

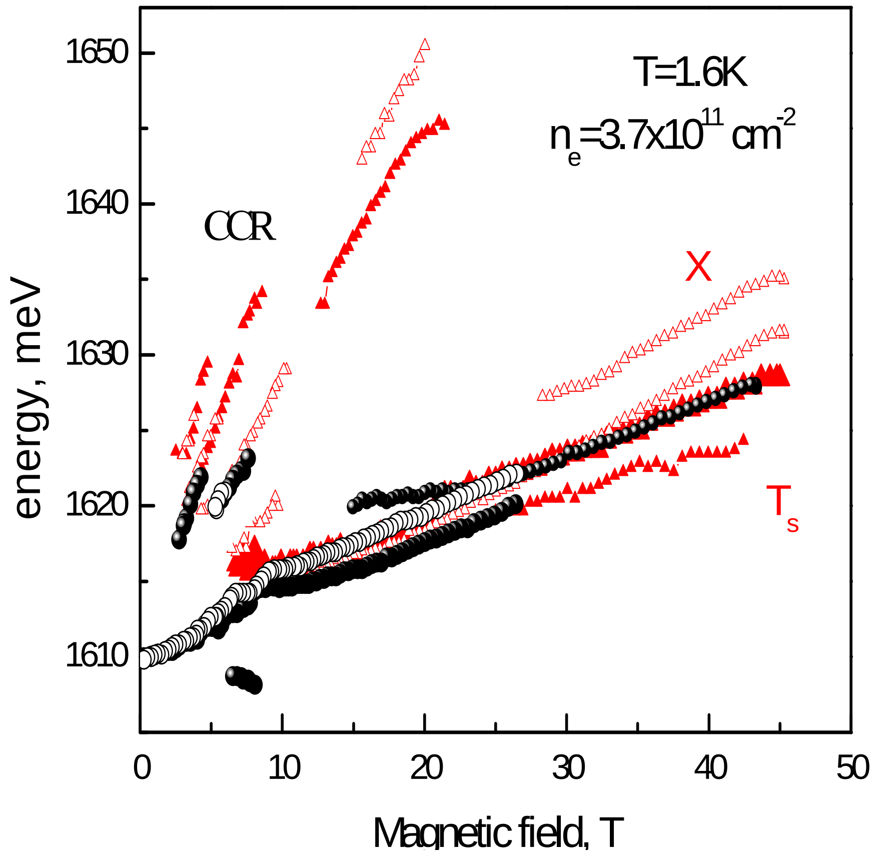


Emission Intensity of CdTe QW m1027, $n_e = 4.7\ 10^{11}\ cm^{-2}$, in s+ at 2K

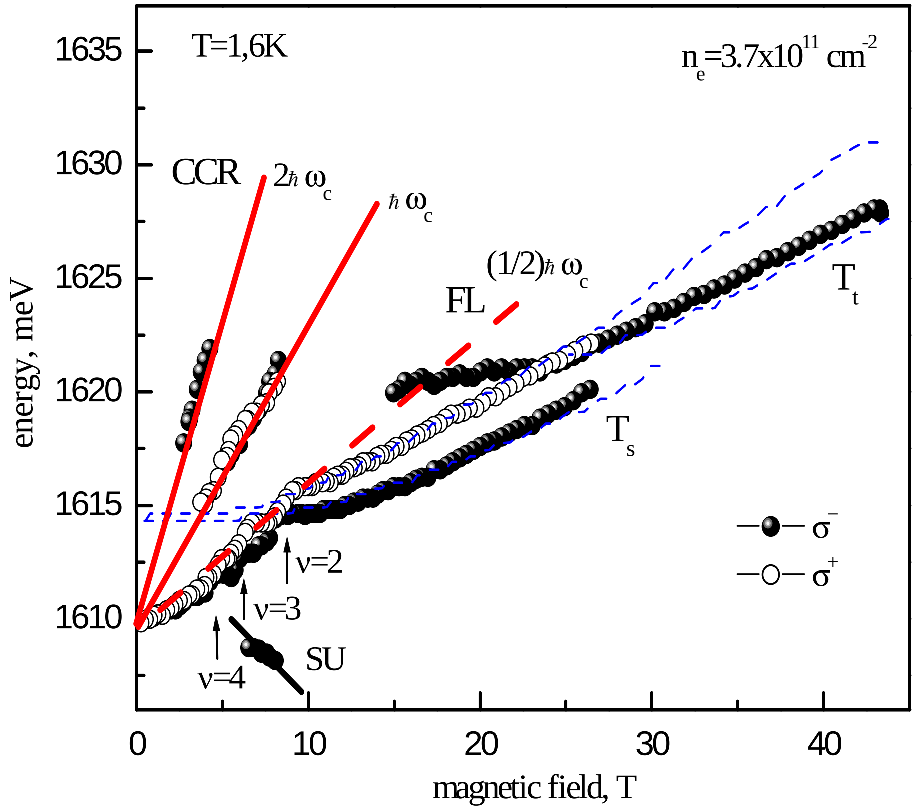
m1207p0to25.data



Combined processes in PL

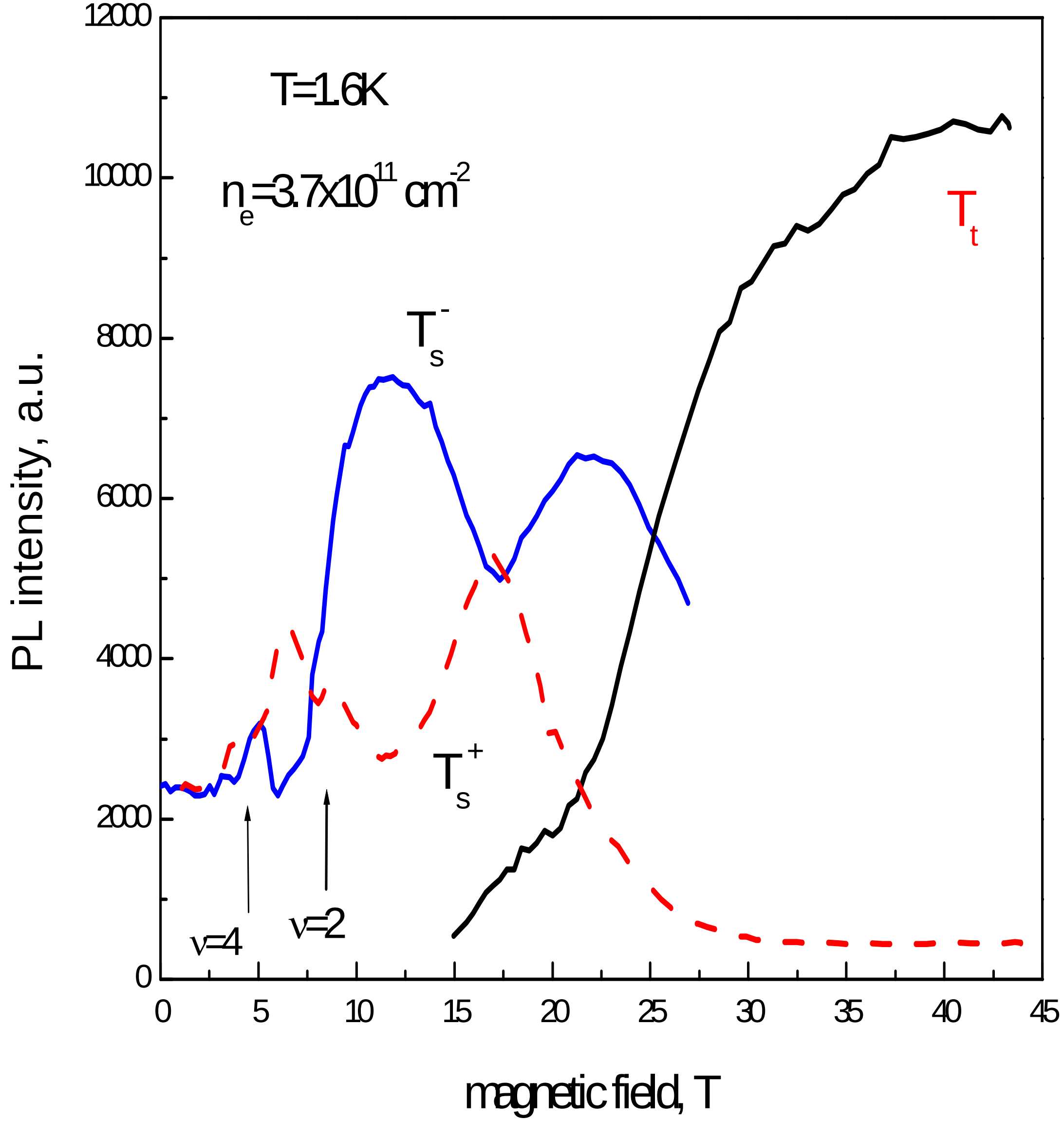


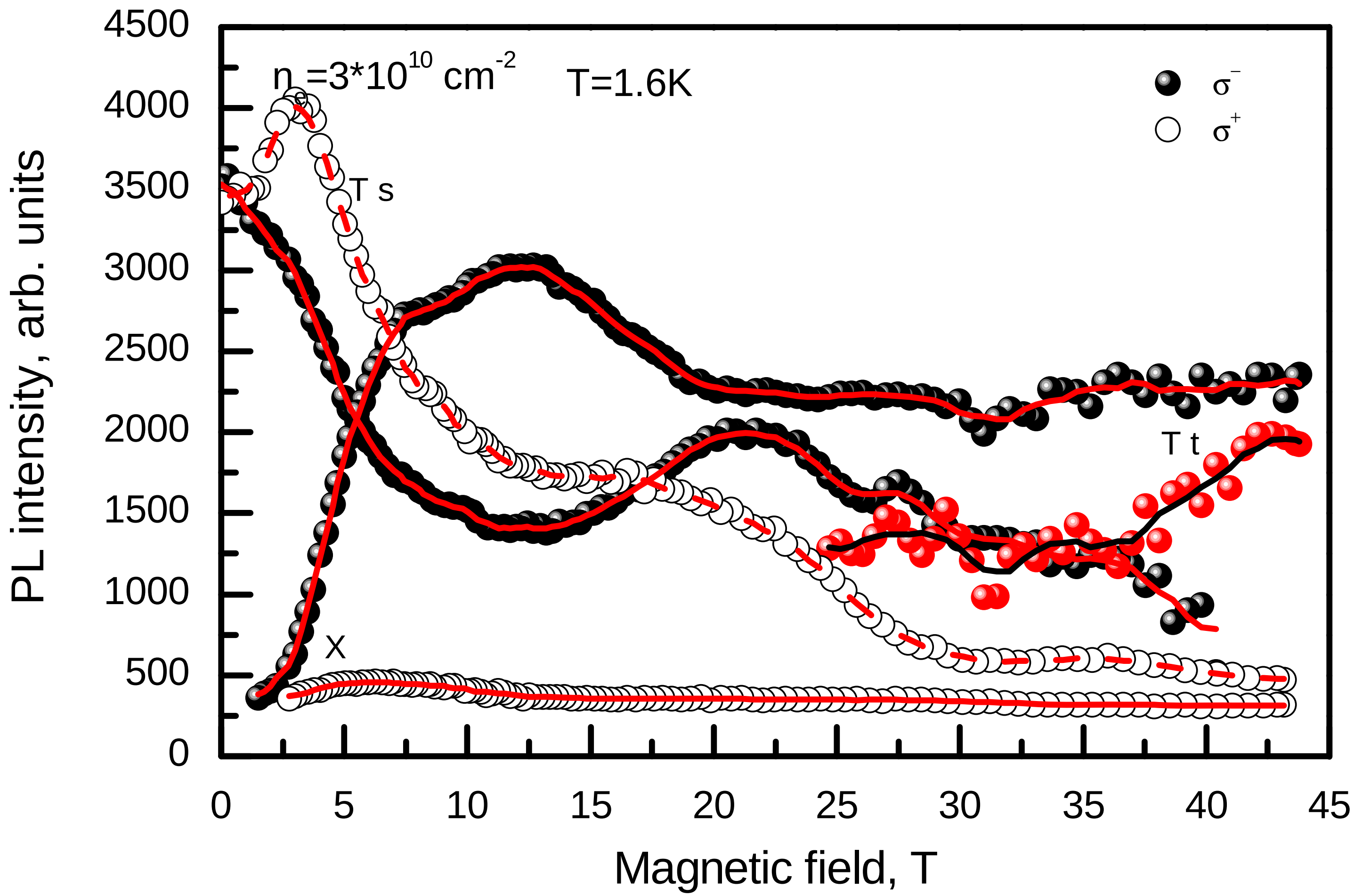
Comparison of PL and reflectivity



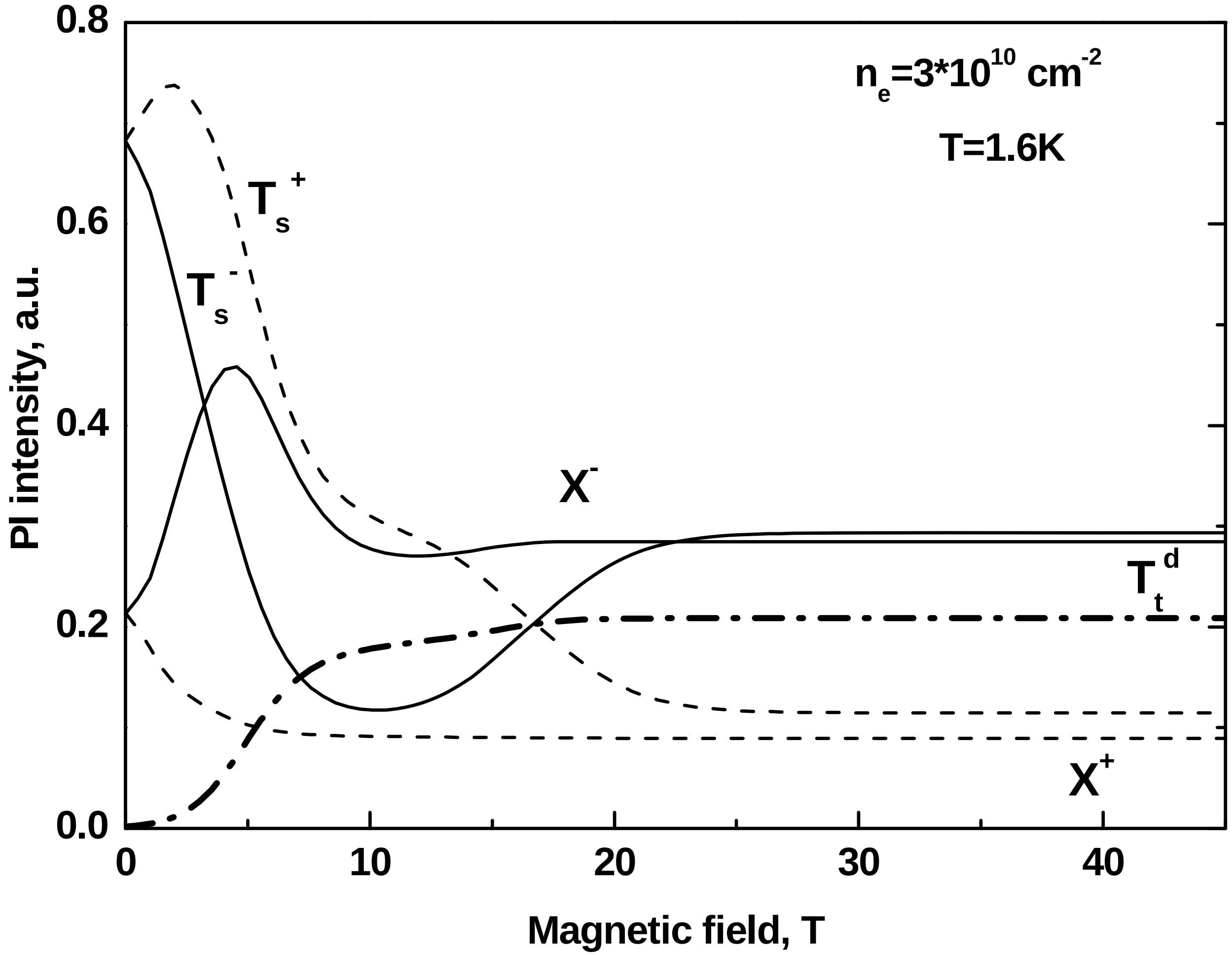
PL and SU

Circular polarization induced by magnetic field





PL intensity, arb. units
Magnetic field, T
n_e=3*10^10 cm^-2
T=1.6K
σ⁻
σ⁺
T s
T t
X

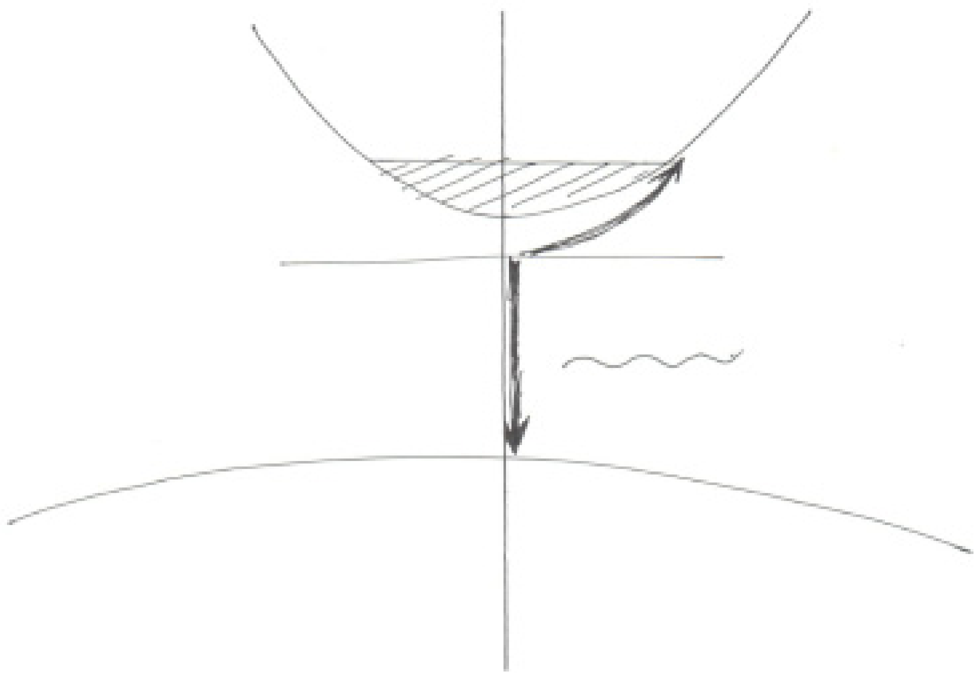

0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
PI intensity, a.u.
Magnetic field, T
n_e=3*10^{10} cm^{-2}
T=1.6K
T_s^+
T_s^-
X^-
T_t^d
X^+

In Emission the initial state is: trion in a ground or excited states;

$$\mathrm{T}r \rightarrow ph + e^{*}$$

the final state is: an electron above Fermi level

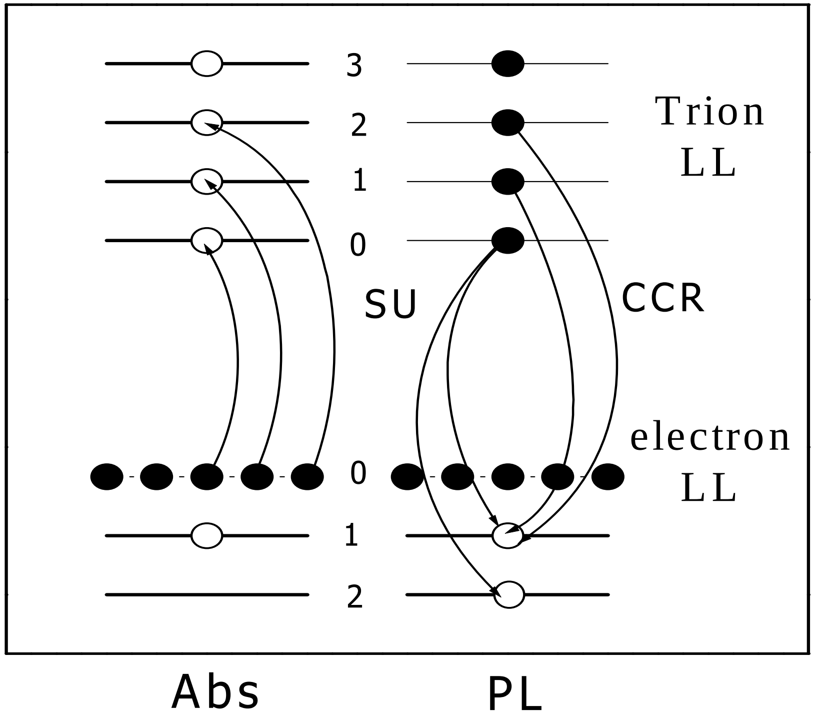
The energy of the transition is $\hbar\omega = E_{Tr} - E^{*} \leq E_{Tr} - E_{F}$



Recombination

In the recombination:

there is a trion in the initial state; in the final state there is photon and one electron on one of the Landau levels



In our magnetic fields we have hierarchy of energies:

$$E_{ex}^{b} >> \hbar\omega_c >> E_{Tr}^{b}$$

where are binding energies of exciton and trion respectively. Hence we can assume that these magnetic fields are small for exciton and strong for trion, and the trion has energies:

$$E_{Tr} = E_{ex} + \left(N + \frac{1}{2}\right)\hbar\omega_c - E_{Tr}^{b}$$

The residual electron after the trion annihilation can have energy:

$$E^{*} = \left(M + \frac{1}{2}\right)\hbar\omega_c$$

, and E^* corresponds to the empty Landau levels above the Fermi level of 2DEG.

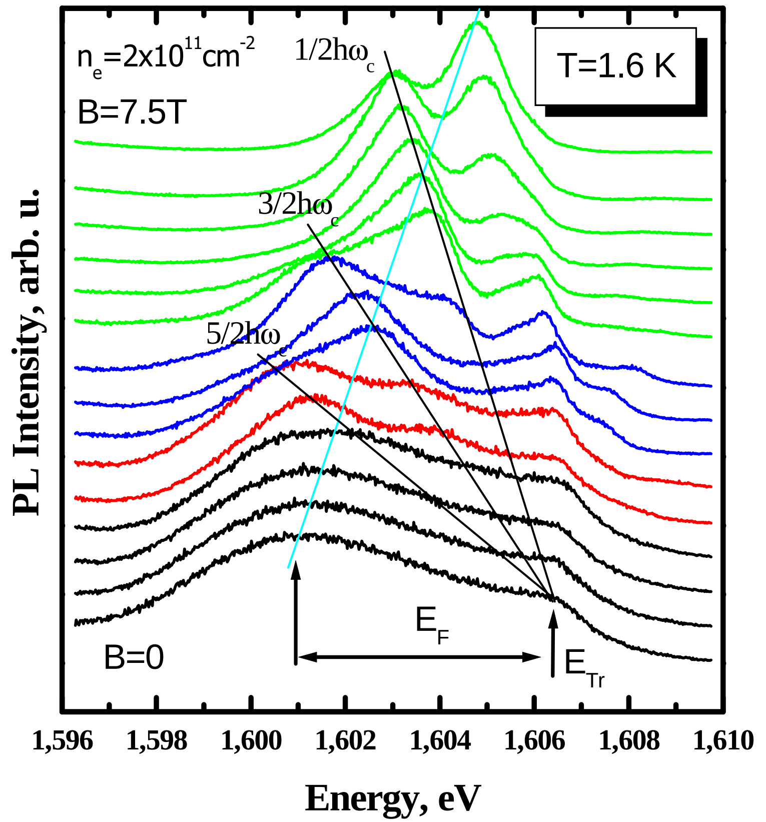
Shake-up

Shake up процессы SU

$$Tr \Rightarrow ph + e^*$$

$$E_{tr} = \hbar\omega + (N + \frac{1}{2})\hbar\omega_e^c$$

$$\hbar\omega = E_{tr} - (N + \frac{1}{2})\hbar\omega_e^c$$



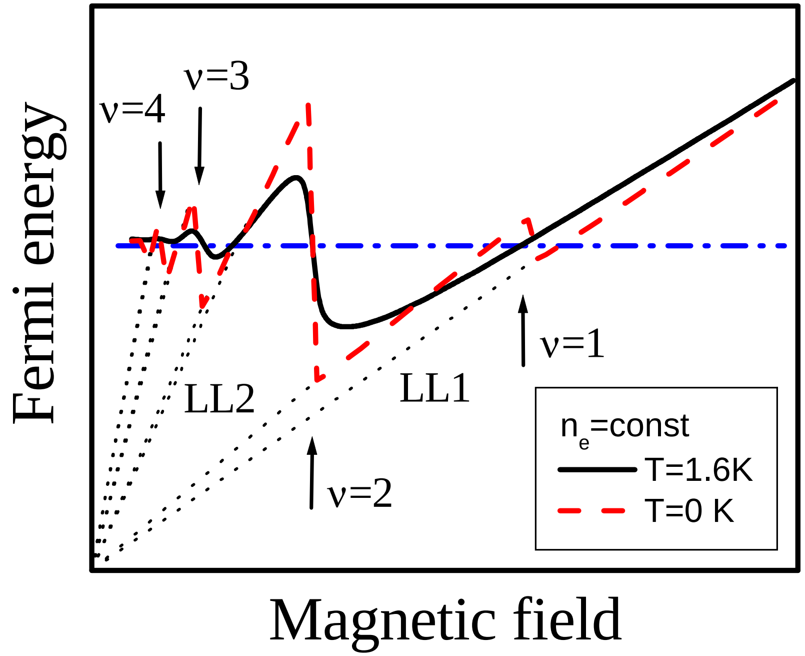
Linear shift of the trion line in magnetic fields

In the final state after the trion recombination a free electron remains. It can appears in the unoccupied states above Fermi level

$$E_{tr} = \hbar\omega + E_F \Rightarrow \hbar\omega = E_{tr} - E_F$$

In magnetic fields the Fermi energy decreases as

$$\frac{1}{2}\hbar\omega_e^c$$



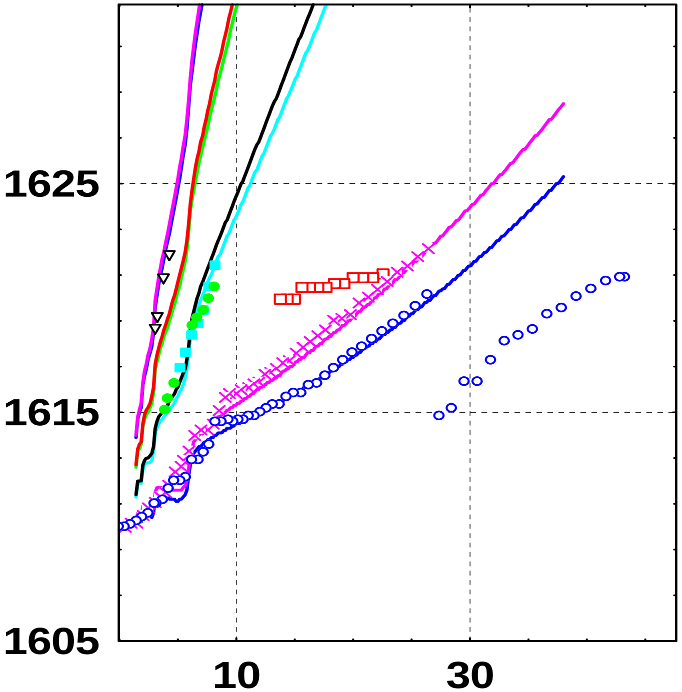
Theory

$$\hbar\omega_{ph}^{\pm} = \hbar\Omega_c(n) - E_{tr} \pm \Delta(B) - E_F(B) + \alpha B + \beta B^2 + E_G$$

Figure gives the energy positions of maxima of emitted bands which are described by equation

The shape of the states in presented by the Gaussian form

$$\rho_n^{\pm}(E) = \frac{eB/(4\pi\hbar)}{\sqrt{2\pi\Gamma_n^2(B)}} \exp\left\{-\left[E - \hbar\omega_{ph}^{\pm}(n)\right]^2 / \left[2\Gamma_n^2(B)\right]\right\}$$



Conclusions

In 2D structures contained electron gas the screening effects are suppressed, and the scattering effects are in contrary enhanced.

Analyzing the optical spectra we shell have in mind that initial and final state of “dark” electron can be different.

In PL the Moss-Burstein shift displays in combined exciton electron processes.

Conclusions

In 2D structures containing electron gas the scattering effects are enhanced.

In the presence of magnetic fields the electron energy spectrum becomes discreet and the scattering processes revel as combined exciton-electron processes.

In such processes we can see directly only the exciton transition but the state of the additional electron, which we can not see, reveals only in the final result.

Combined processes in

Dense 2DEG

Three electrons+one

hole states

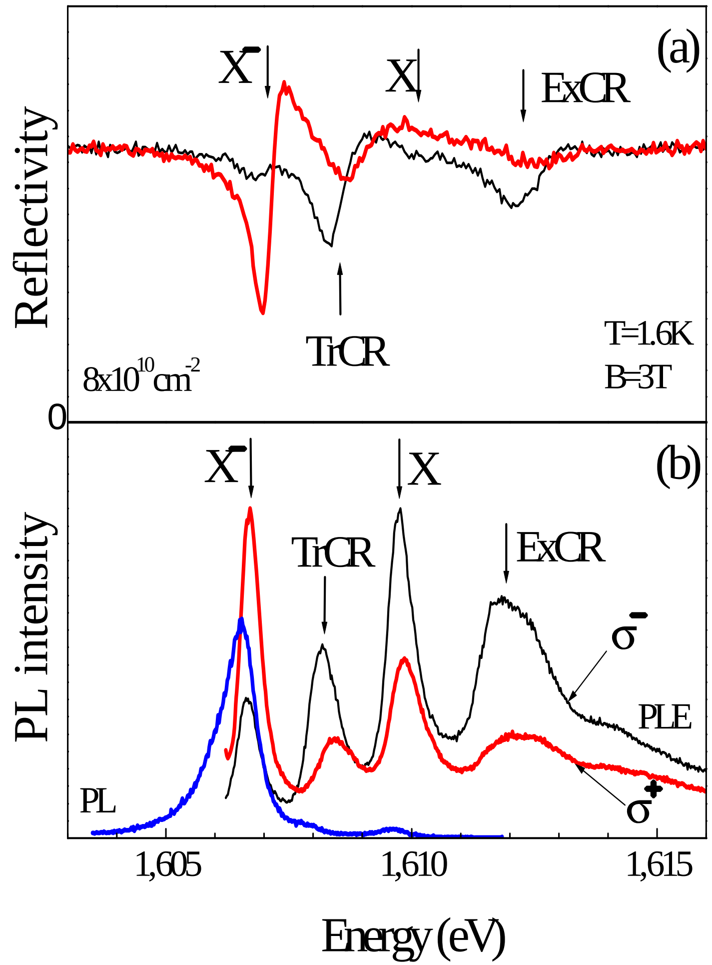
In the dense 2DEG two-electron processes emerge in the spectra **TrCR**

There are two electrons in the initial state; an incident photon creates an exciton which binds with one of the electrons forming a trion; and the second electron excites on the second Landau level

$$e + e + ph \Rightarrow Tr + e^*$$

$$\frac{1}{2}\hbar\omega_e^c + \frac{1}{2}\hbar\omega_e^c + \hbar\omega = E_{tr} + \frac{3}{2}\hbar\omega_e^c$$

$$\hbar\omega = E_{tr} + \frac{1}{2}\hbar\omega_e^c$$



Trion Cyclotron Resonance