Lection 6

6). Excitons in the presence of electron gas (2h)
(bound states - trions, triplet and singlet trions, unbound states, combined exciton electron processes; manifestation of exciton electron scattering in optical spectra)
7). Biexcitons (1h)

EXCITONS IN 2DEG

Low electron density limit

- **1. Charged exciton-electron complexes (trions)**
- **2. Singlet and triplet trion states**
- **3. Modulation doped QWs**
- **4. Trions in optical spectra**
- **5. Action of magnetic fields on the trions**

High electron density limit

- **6. Combined exciton cyclotron resonance**
- **7. Combined trion cyclotron resonance**
- **8. Combined exciton electron processes in PL spectra**
- **9. Trion Zeeman splitting**

From LOW density to HIGH density

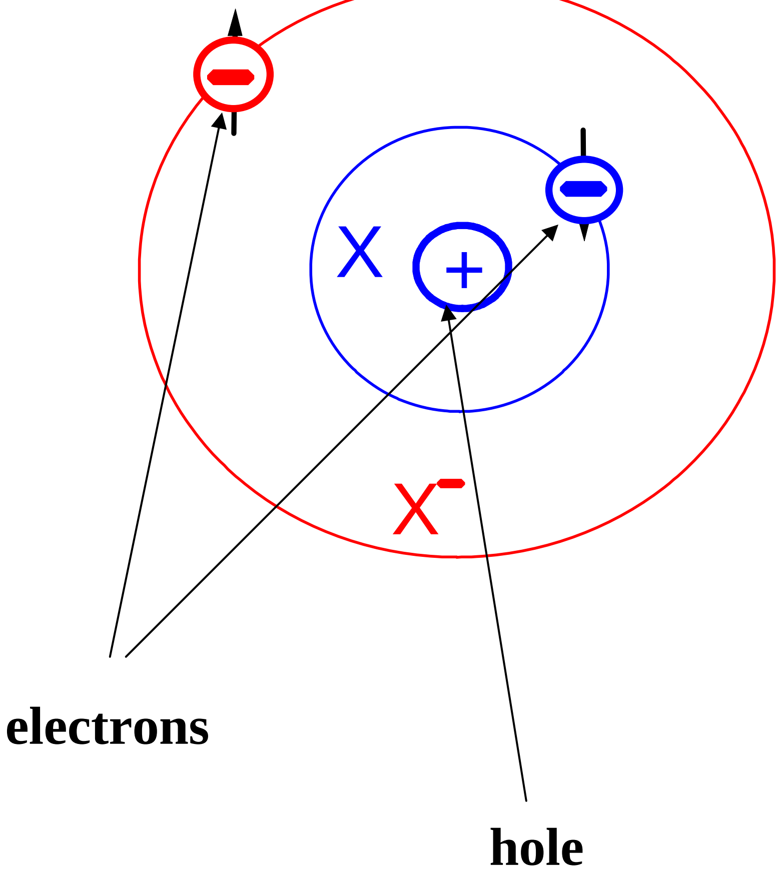
LOW 2DEG DENSITY

Two electrons+one hole states

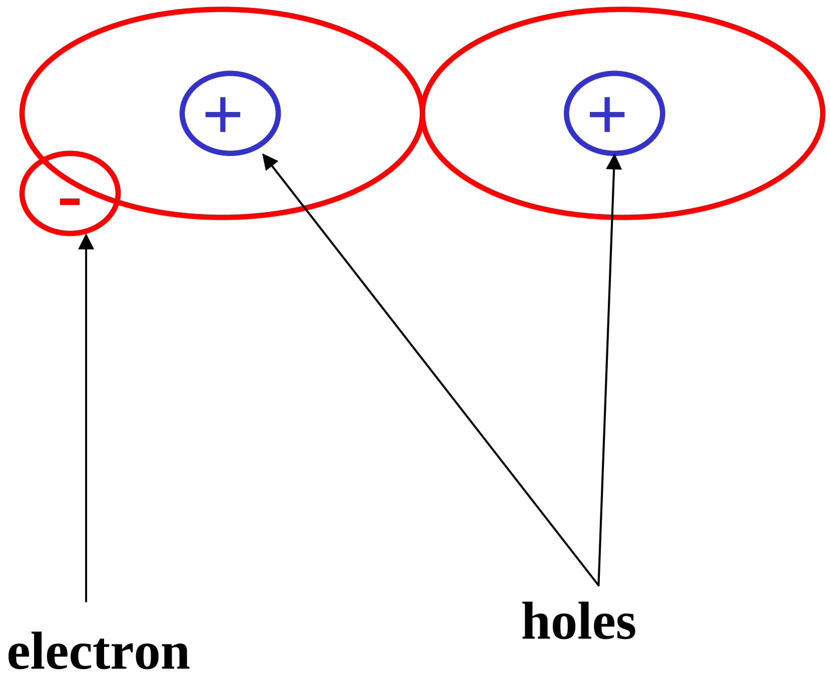
- Trions
- Trions in magnetic fields
- Trion excited states in magnetic fields

Charged exciton – electron complex (trion)

Negatively charged Trion X^-
similar to ion H-



Positively charged Trion X^+
Similar to ionized molecule H+



Singlet and Triplet trion states

Wavefunction for two electrons in the trion

$$\varphi(1,2) = U(1,2)\chi(1,2)$$

Spatial part of the wavefunction

$$U_{nlm}^{0} = \frac{1}{\sqrt{2}}\left[u_1(\vec{r}_1)u_{nlm}(\vec{r}_2) \pm u_1(\vec{r}_2)u_{nlm}(\vec{r}_1)\right]$$

S_z = +1
S_z = 0
S_z = -1
triplet

S_z = 0
singlet

Singlet state + **S_z = 0** $\propto e^{-\alpha(\vec{r}_1 + \vec{r}_2)}$

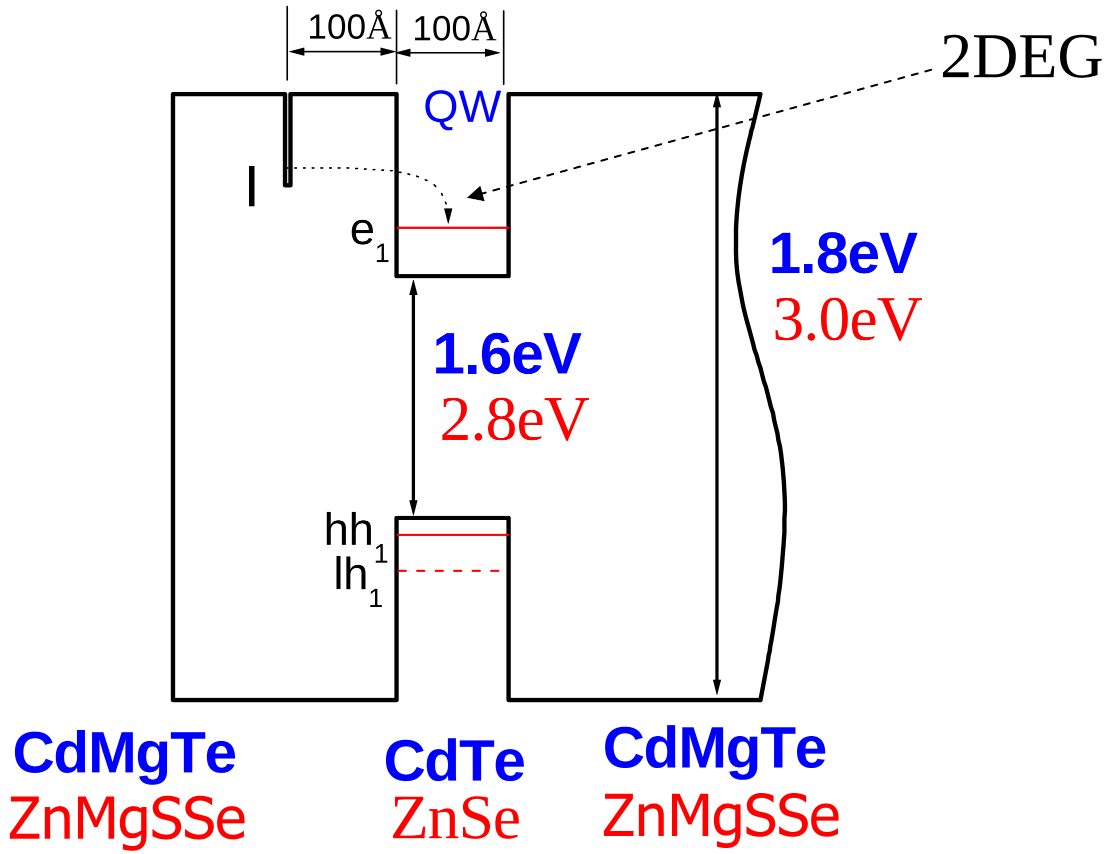
Triplet state - **S_z = ±1,0**

$U_{nlm} \neq 0$, if $l \neq 0$ one electron is in *1S* and the second is in *2P* state – dark triplet

Or if n $\neq 1$ one electron is in *1S*, and the second is in a *2S* state bright triplet

Experimental studies of trions

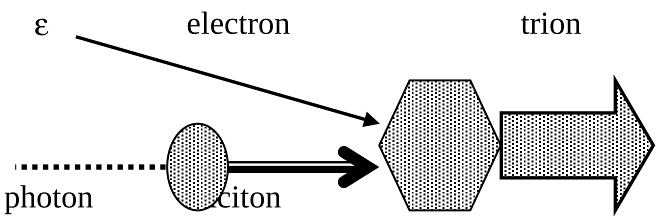
Modulation doped structures

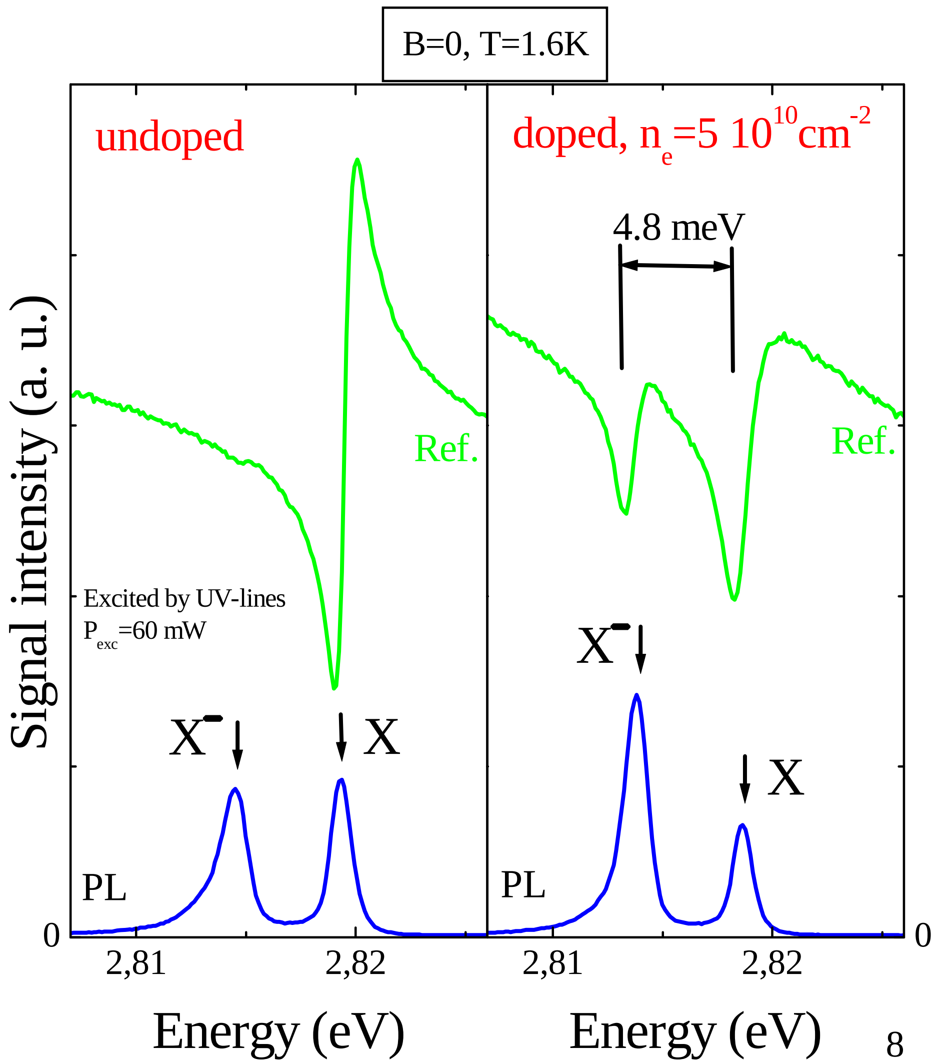


2DEG density varied from $\mathbf{n_e=5*10^9}$ **см$^{-2}$** to **$9*10^{11}$ см$^{-2}$**

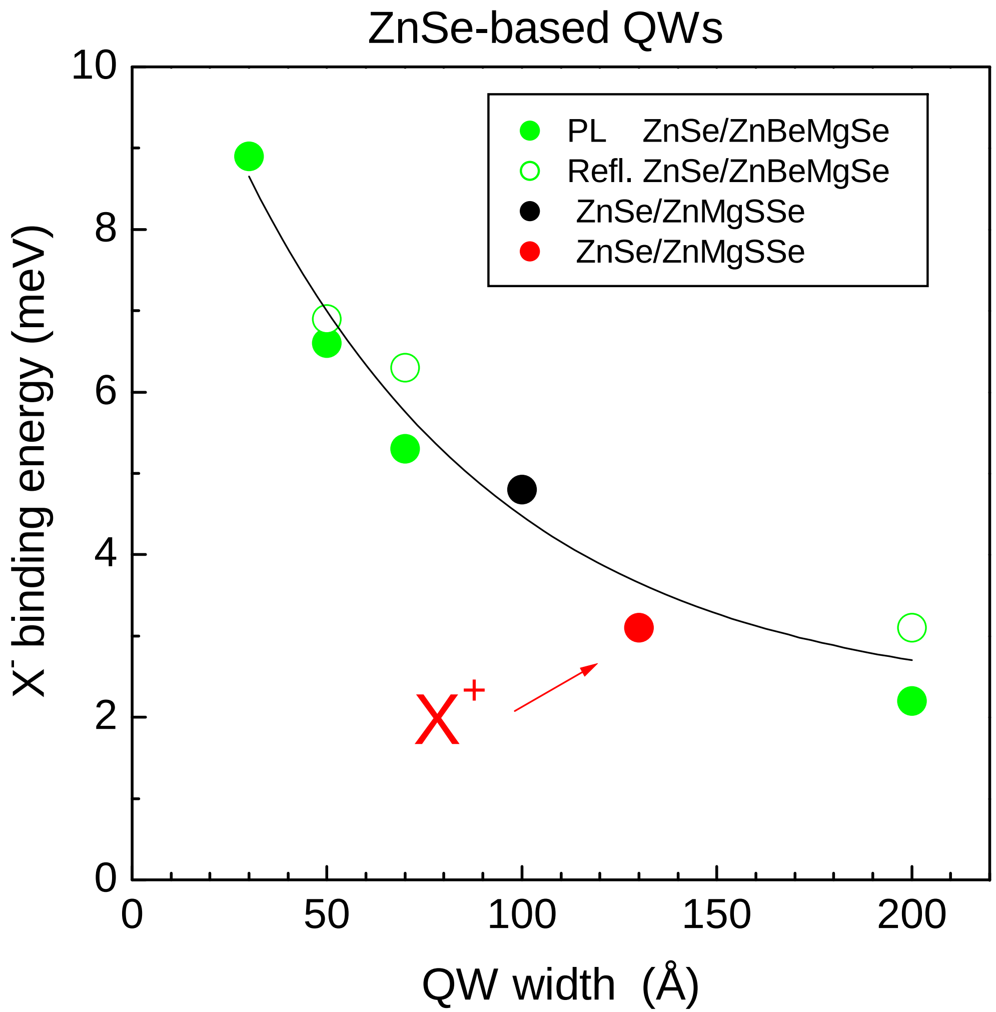
Optical processes with the trion participation

Trion formation time in ZnSe structures is of the order of 2 –4 psec



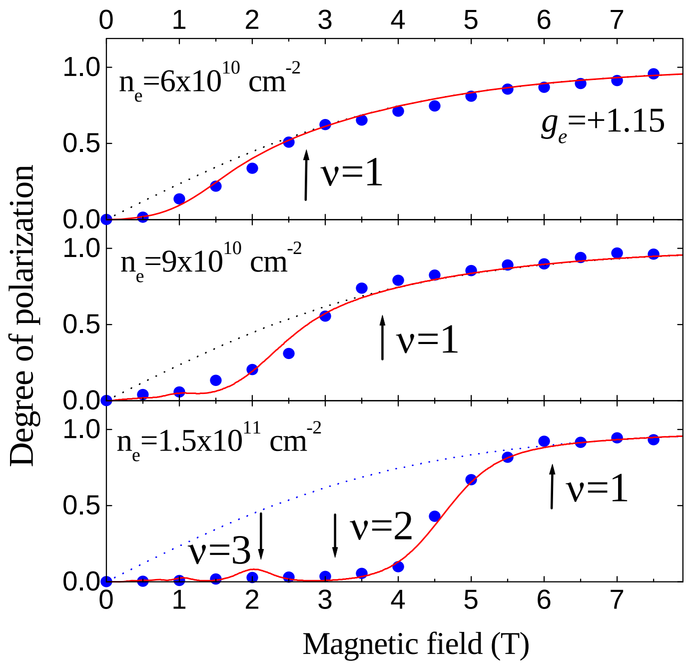


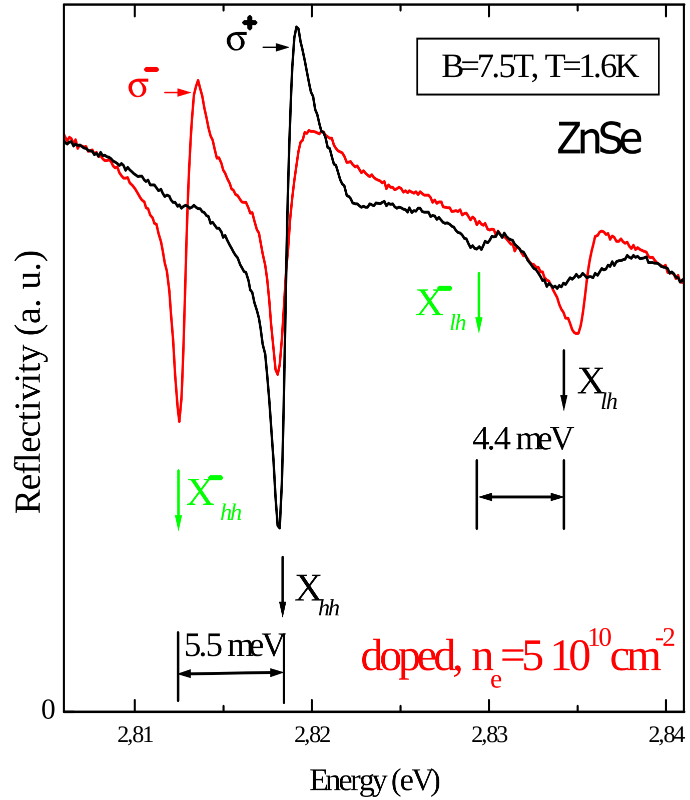
Trion binding energy as a function of the QWwidth



Trion states in magnetic fields

Singlet trion in magnetic fields

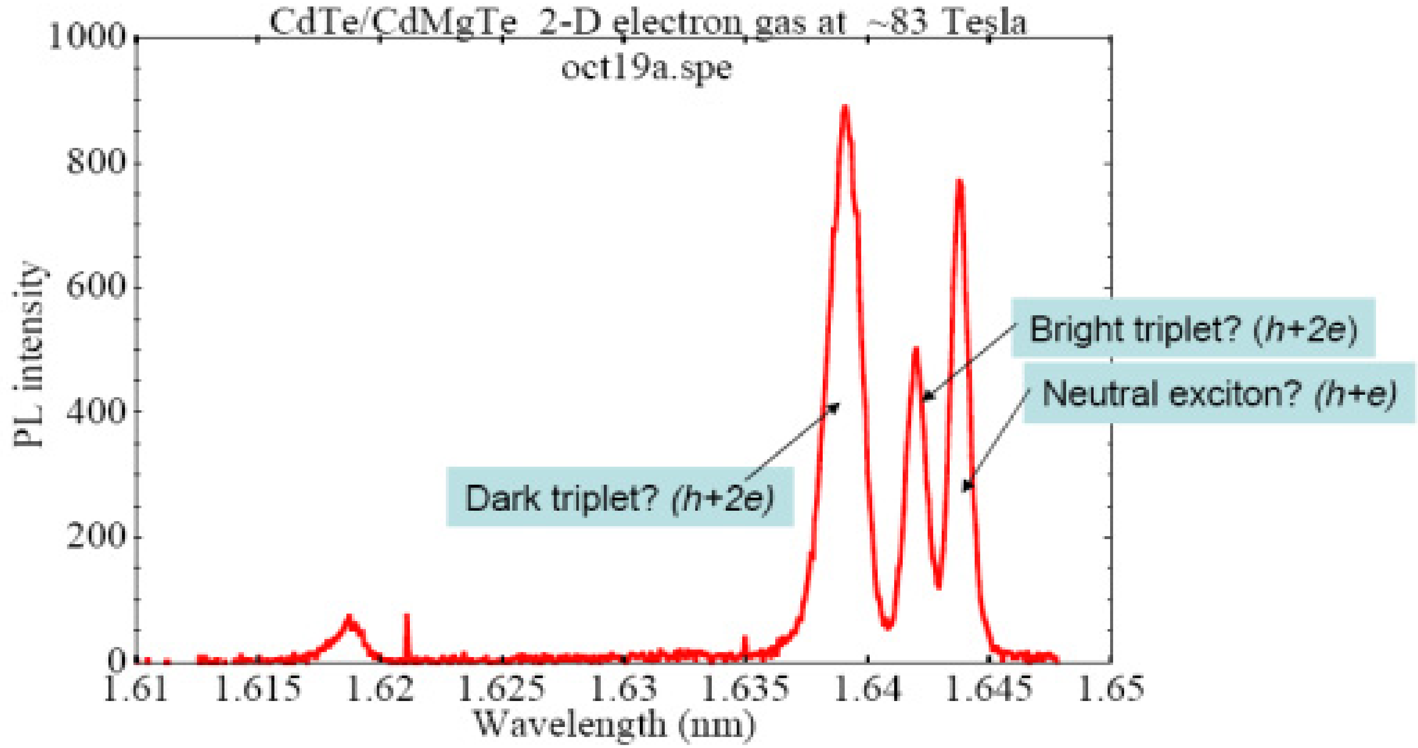




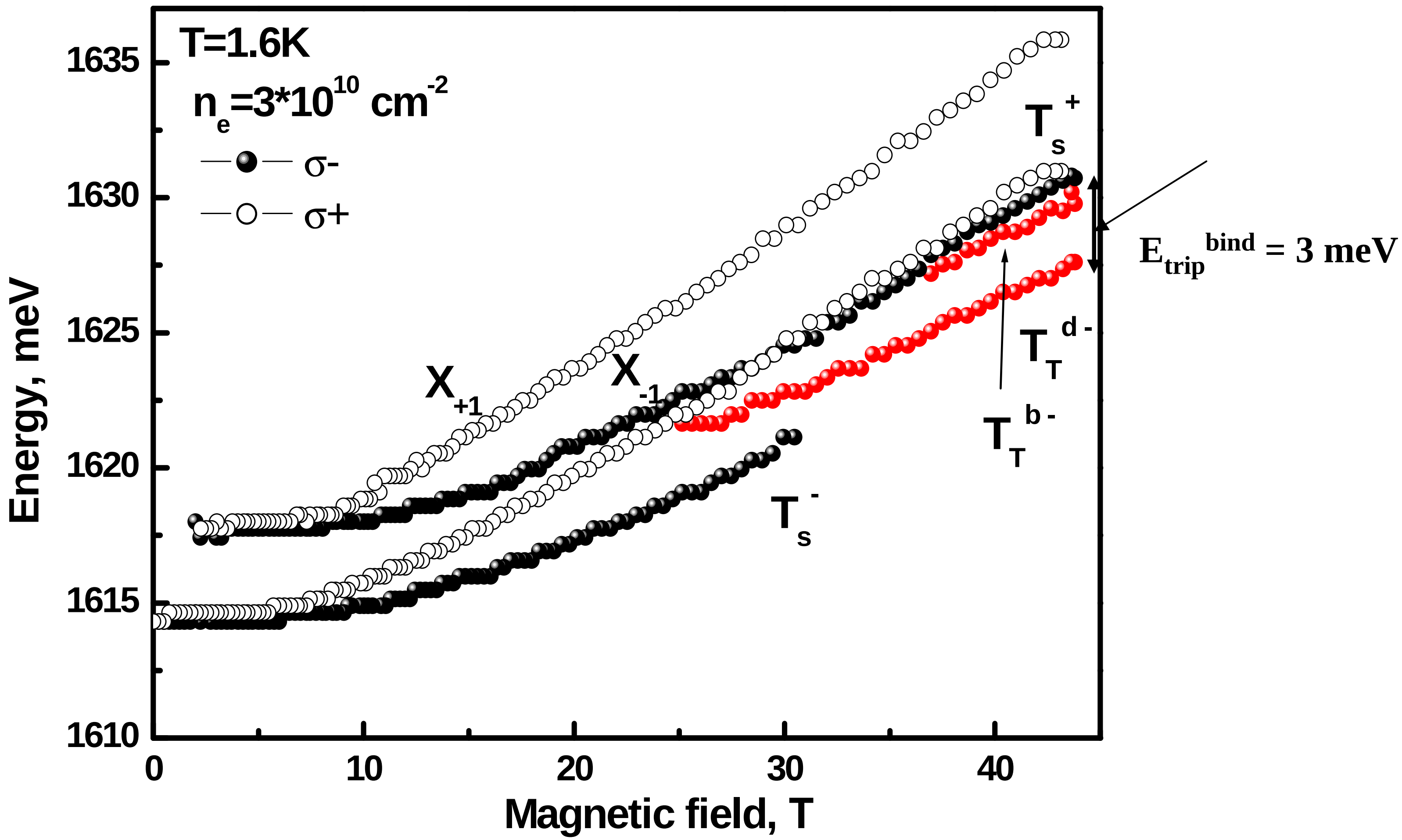
The circular polarization of the trion absorption (reflectivity line) in magnetic fields can be used to determine electron concentration by pure optical method

X^-_{hh} and X^-_{lh} resonances appear in opposite circular polarizations

PL spectra: CdTe/CdMgTe 2D electron gas at 1.5 K at ~83 T (in 100T LP)



Singlet and Triplet in high fields

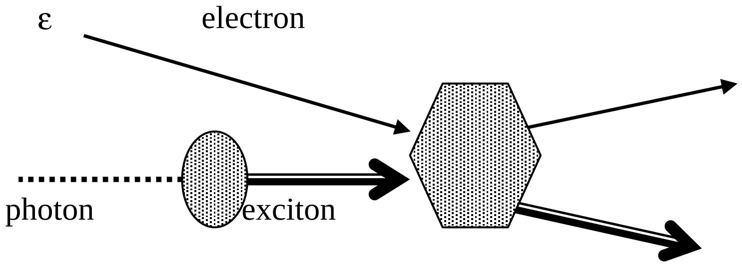


EXCITON-ELECTRON SCATTERING

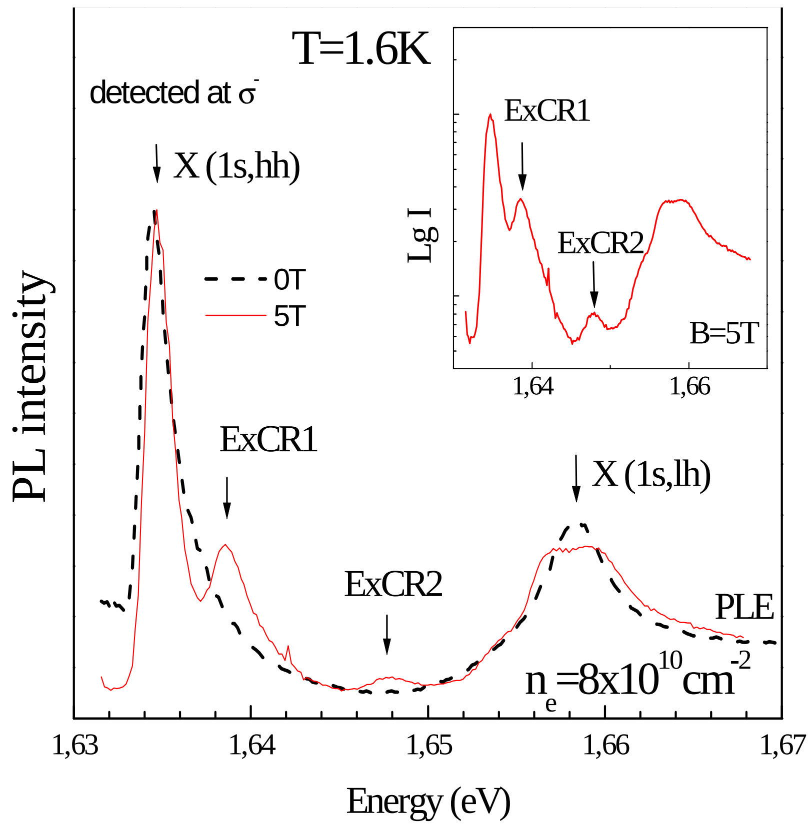
(excited states of a trion in magnetic fields)

Exciton – electron scattering

Exciton – electron scattering

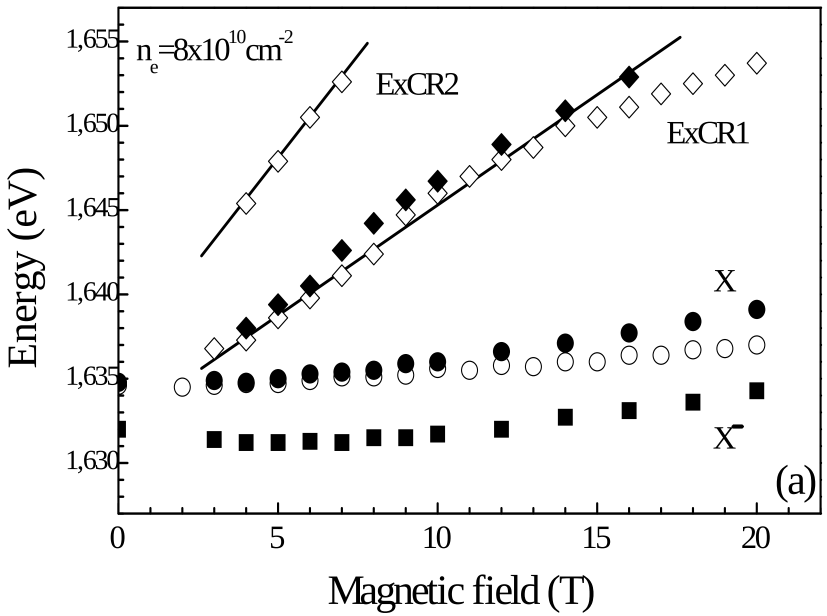


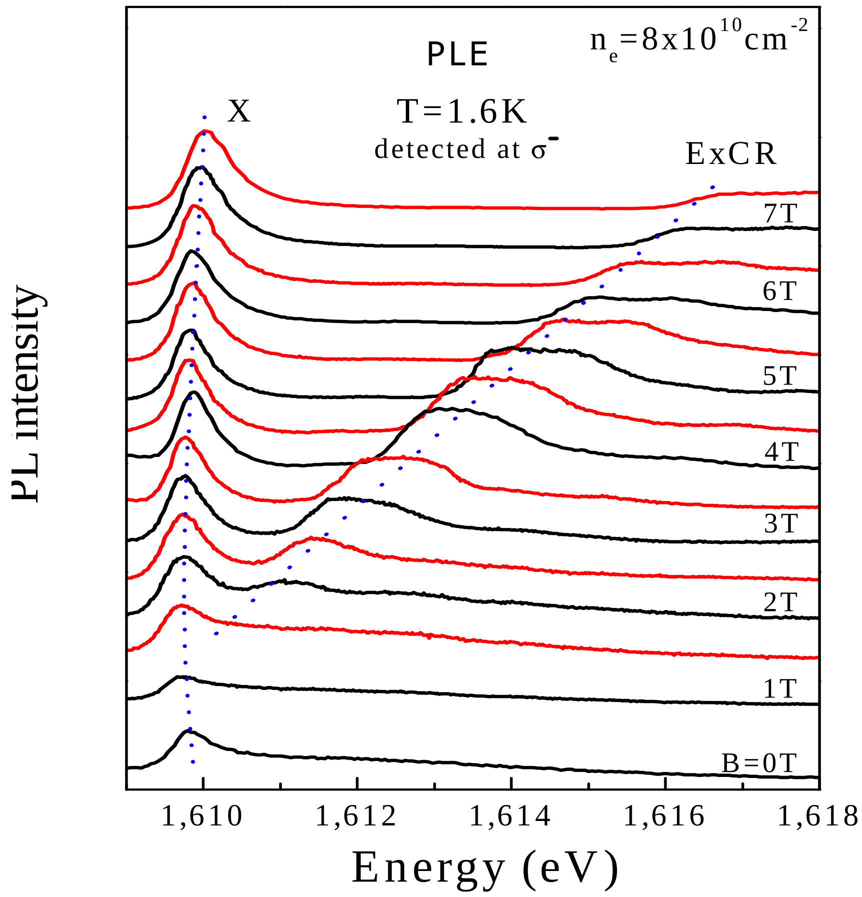
In magnetic fields in QWs the exciton electron scattering leads to the electron transitions between Landau levels - **ExCR**



The scattering leads to high energy tail of the exciton absorption line. In magnetic fields it splits into separate lines because the electron spectrum becomes discrete = excited states of trions in magnetic fields.

Combined exciton –cyclotron resonance ExCR





The ExCR line shifts LINEARLY from the exciton resonance to high energies with increase of magnetic fields

$$\hbar\omega_{ExCR} = N\hbar\omega_e^c(1+\frac{m_e}{M})$$

With increase of the electron density there is redistribution of absorption from exciton to trion and ExCRC

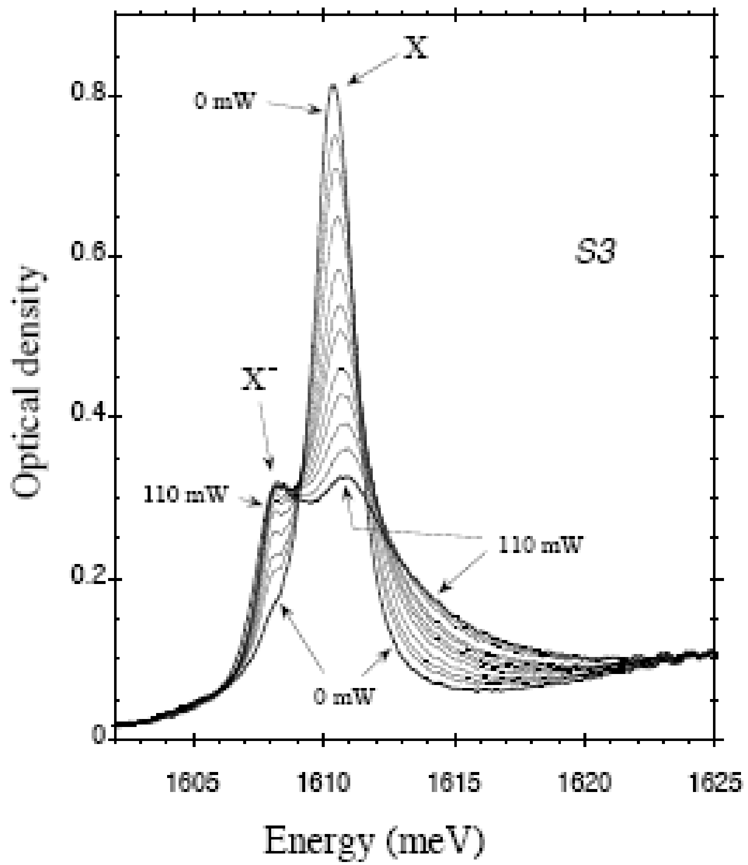


FIG. 3: Optical Density $\log_{10}(1/t)$ of CdTe/CdZnTe MQW sample S3 at $B = 0$, nominal $T = 2$ K, for various pump powers, showing increase of trion absorption peak and decrease and asymmetric broadening of exciton peak with increasing n_e.

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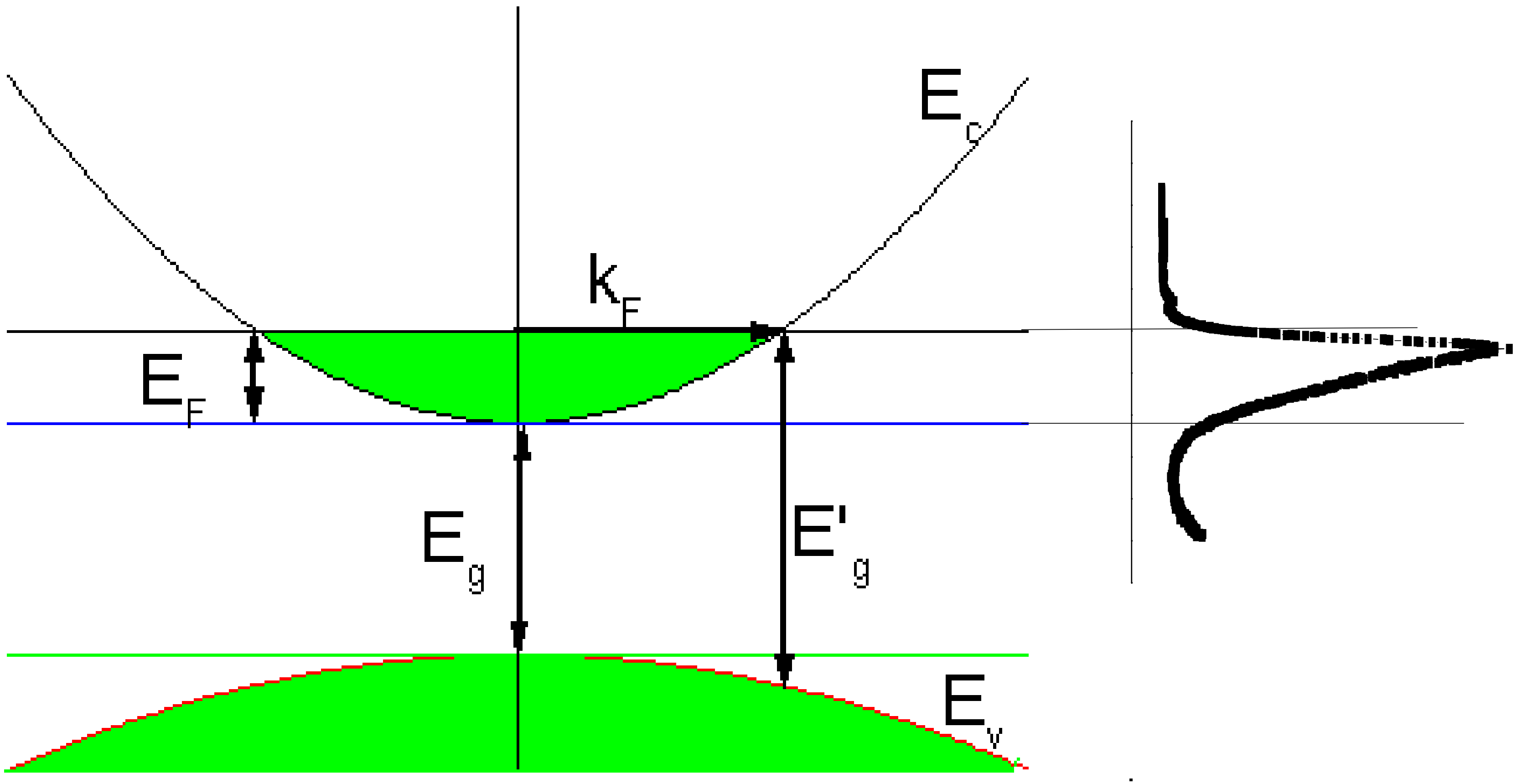
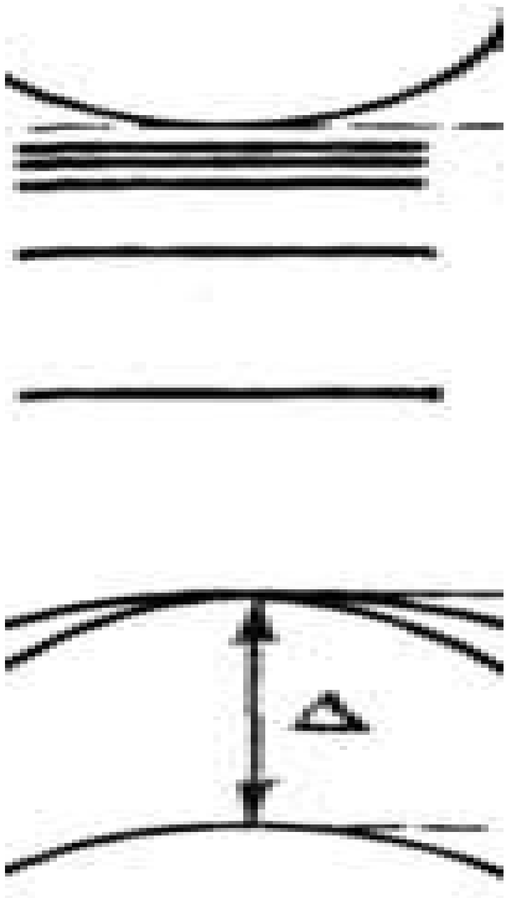
WHAT IS THE BURSTEIN-MOSS SHIFT?

Photoluminescence

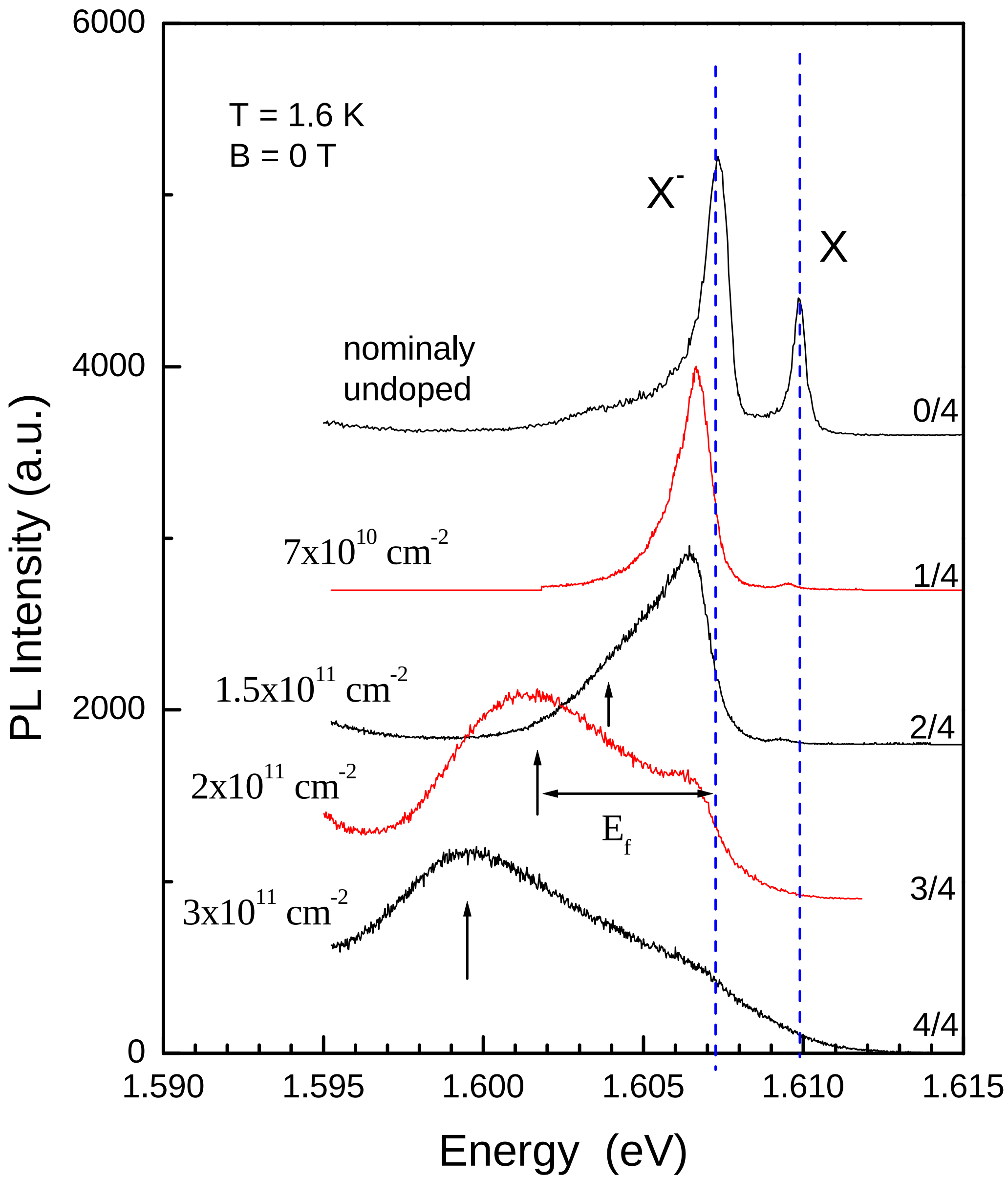
Conventional scheme of the B-M shift



Where is the exciton here?

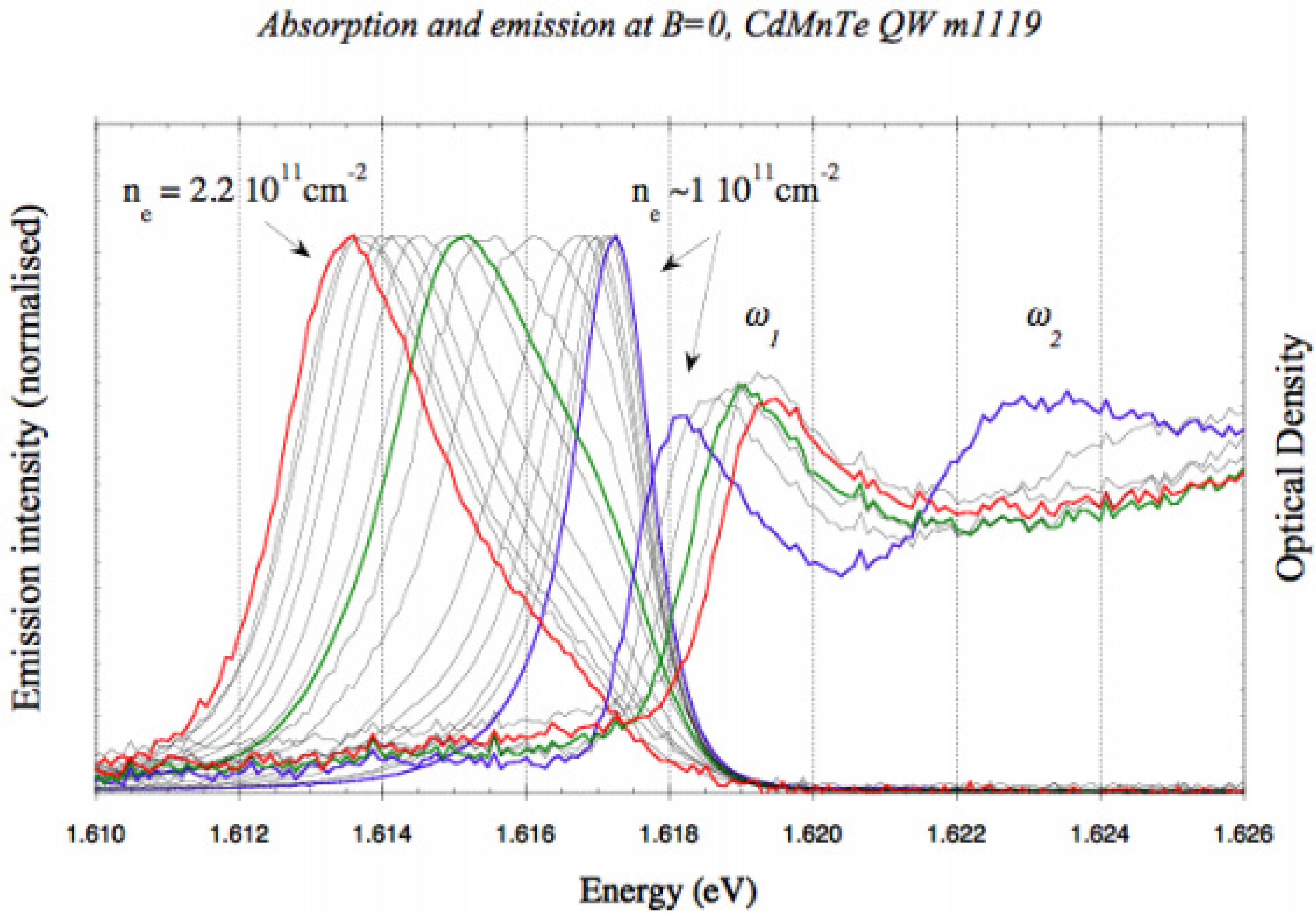


PL as a function of the electron concentration

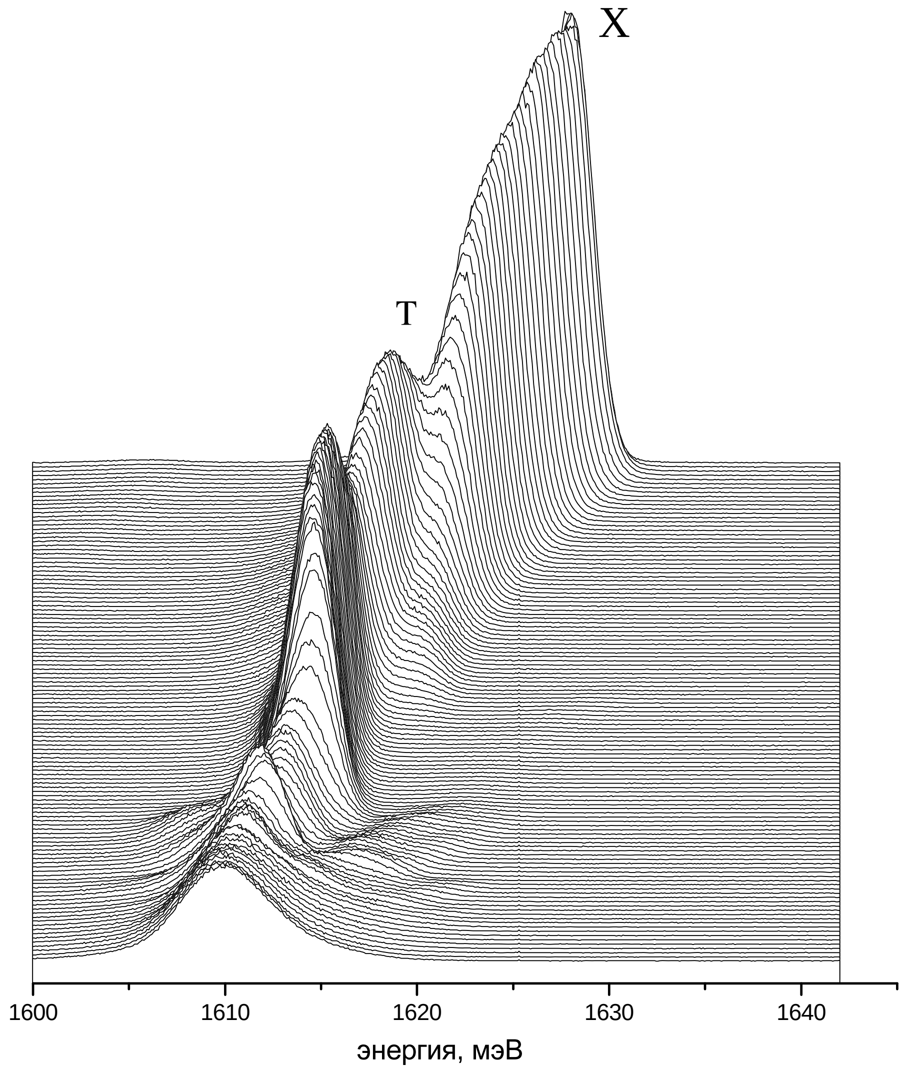


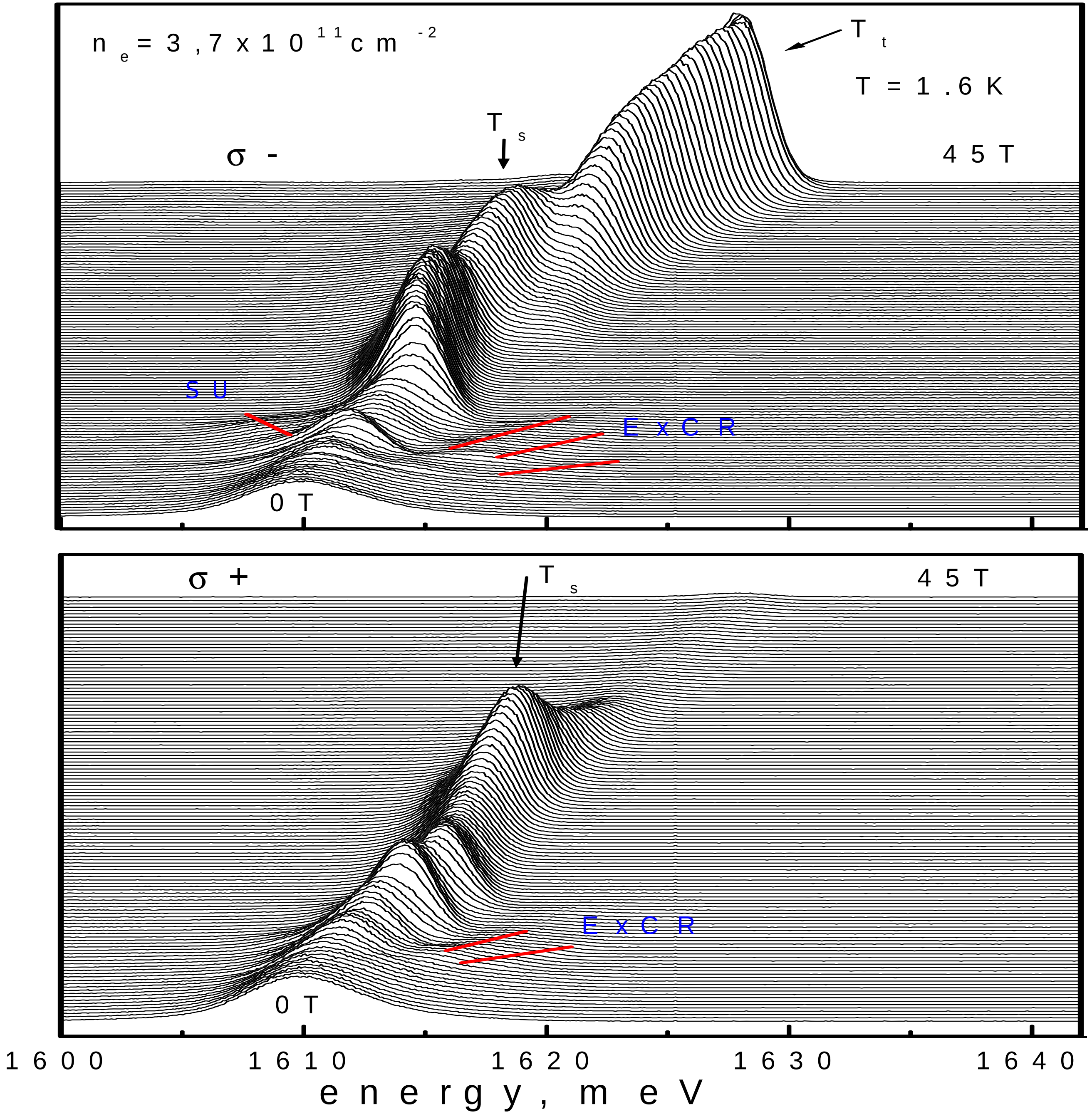
$E_b^{ex} >> E_F$

$E_b^{tr} \sim E_F$


Absorption and emission at B=0, CdMnTe QW m1119
$n_e = 2.2\ 10^{11} cm^{-2}$
$n_e \sim 1\ 10^{11} cm^{-2}$
ω_1
ω_2
Emission intensity (normalised)
Optical Density
1.610
1.612
1.614
1.616
1.618
1.620
1.622
1.624
1.626
Energy (eV)

“Recreation” of the exciton and trion lines in magnetic field





$n_e = 3,7 \times 10^{11} cm^{-2}$
T_t
T = 1.6 K
T_s
σ -
45 T
SU
ExCR
0 T
σ +
T_s
45 T
ExCR
0 T
1600
1610
1620
1630
1640
energy, meV