EXCITON g-FACTOR IN QUANTUM WELLS

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G-factor is a coefficient of proportionality between classical giromagnetic ratio and real one

$$\mu = g\mu_0 = g\frac{e}{2mc}$$

Giromagnetic ratio is a ratio of magnetic and mechanical momenta

$$\vec{\Omega} = \mu\vec{H}$$

Electron g-factor

Consider effective mass Hamiltonian for electron

$$H_{ij} = \frac{\hbar^2 k^2}{2m_0}\delta_{ij} + \frac{\hbar^2}{m^2}\sum_i \frac{(\mathbf{K}\cdot\mathbf{p}_{ji})(\mathbf{K}\cdot\mathbf{p}_{ij})}{\varepsilon_0(0)-\varepsilon_i(0)} + \mu g_0(\hat{\boldsymbol{\sigma}}_{ij}\cdot\mathbf{B})$$

Will take into account magnetic field by substitution

$$\mathbf{K} = \mathbf{k} + \frac{e}{c}\mathbf{A}(\mathbf{r}) \qquad\qquad \mathbf{A}(\mathbf{r}) = \frac{1}{2}[\mathbf{B}\times\mathbf{r}]$$

Split $\mathbf{K}\cdot\mathbf{p}$ Term on symmetric and anti-symmetric parts

$$\frac{\hbar^2}{m_0^2}\sum_i \frac{\mathbf{K}\cdot\{\mathbf{p}_{ji}\cdot\mathbf{p}_{ij}\}\cdot\mathbf{K}}{\varepsilon_0(0)-\varepsilon_i(0)} - i\frac{1}{m_0^2}\frac{e\hbar}{2c}\mathbf{B}\cdot\sum_i \frac{[\mathbf{p}_{ji}\cdot\mathbf{p}_{ij}]}{\varepsilon_0(0)-\varepsilon_i(0)}$$

We obtain for effective mass and g-factor

$$\frac{1}{m_c^*} - \frac{1}{m_0}\sum_i \frac{\left|P_{ci}^x\right|^2}{\varepsilon_c(0)-\varepsilon_i(0)} \qquad\qquad g = \frac{e}{2m_0^2 c}\sum_i \frac{P_{ci}^x P_{ic}^y - P_{ci}^y P_{ic}^x}{\varepsilon_c(0)-\varepsilon_i(0)}$$

Exciton g-factor

$$g_{exc} = g_e + g_h + g_{orbital}$$

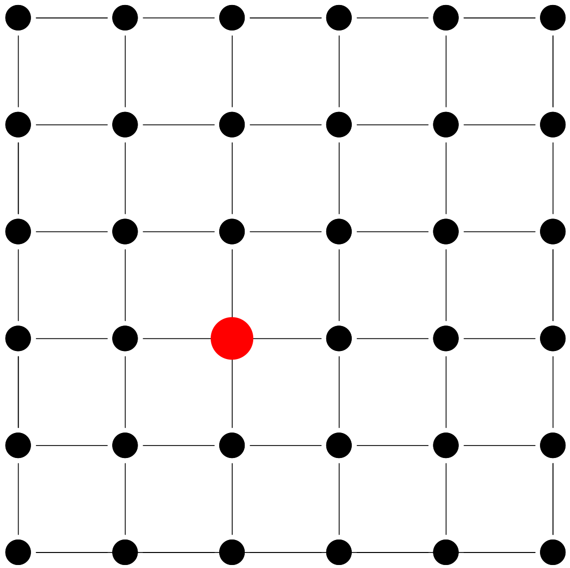
One should have in mine that for orbital motion contrary to the g factor of electron (hole) we have effective mass in the denominator!

$$\frac{e}{2m^* c}$$

For exciton Zeeman splitting one can obtain

$$\frac{e}{2c}\left(\frac{1}{m_e} - \frac{1}{m_h}\right)(\vec{H} \cdot \vec{L})$$

Exciton can travel in crystal completely free



If we will create exciton with definite moment it will move with this K vector

The main property of exciton is its mobility

Let consider all possible corrections to the exciton g-factor that depend on exiton wave vector K or K^2

Will use theory of irredusible tensors

The idea of this method is that:
An arbitrary tensor can be split on irredusible tensors which are transforming by the same way.

For example: second rank tensor splits on scalar + vector + symmetric tensor of the second rank

Third rank tensor can be split on 1) scalar, 2) three vectors, 3) two tensors of the second rank and one symmetric tensor of the third rank

Because magnetic field transforms as a pseudo-vector

We have to construct all possible pseudo-vectors from the products

$$K_i H_j \quad and/or \quad K_i K_j H_l$$

$K_i H_j$ can not give any pseudo-vector

Home task:

Construct symmetric tensor from the product

$$K_i H_j$$

(*This term will be the considered of my presentation in OECS*13)

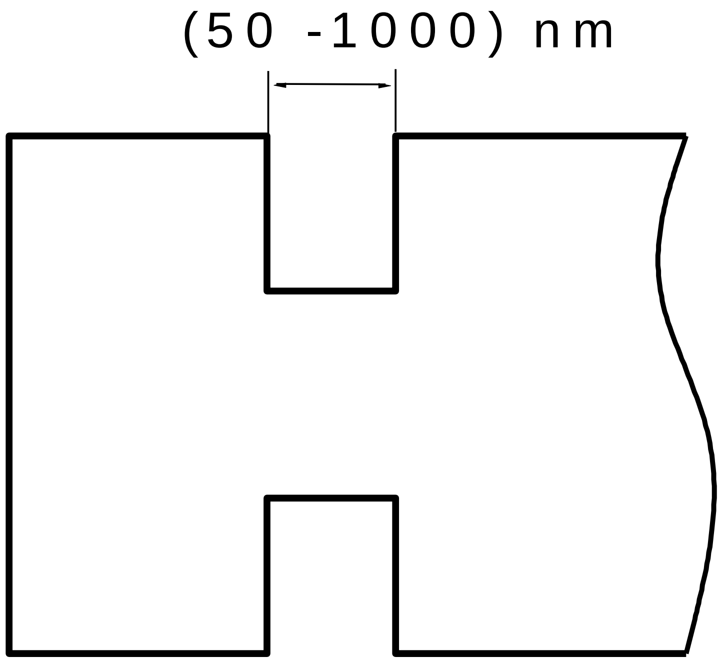
The terms proportional to $K_i K_j$ are:

Γ_4	$K^2 H_x$ $K^2 H_y$ $K^2 H_z$
Γ_4	$2(2K_x^2 - K_y^2 - K_z^2)H_x$ $2(2K_y^2 - K_x^2 - K_z^2)H_y$ $2(2K_z^2 - K_x^2 - K_y^2)H_z$
Γ_4	$\{K_x K_y\}H_y + \{K_x K_z\}H_z$ $\{K_y K_z\}H_z + \{K_x K_y\}H_x$ $\{K_z K_x\}H_x + \{K_z K_y\}H_y$

We can expect the $\sim K^2$ corrections to the g-factor both in Faraday and Voigt geometry

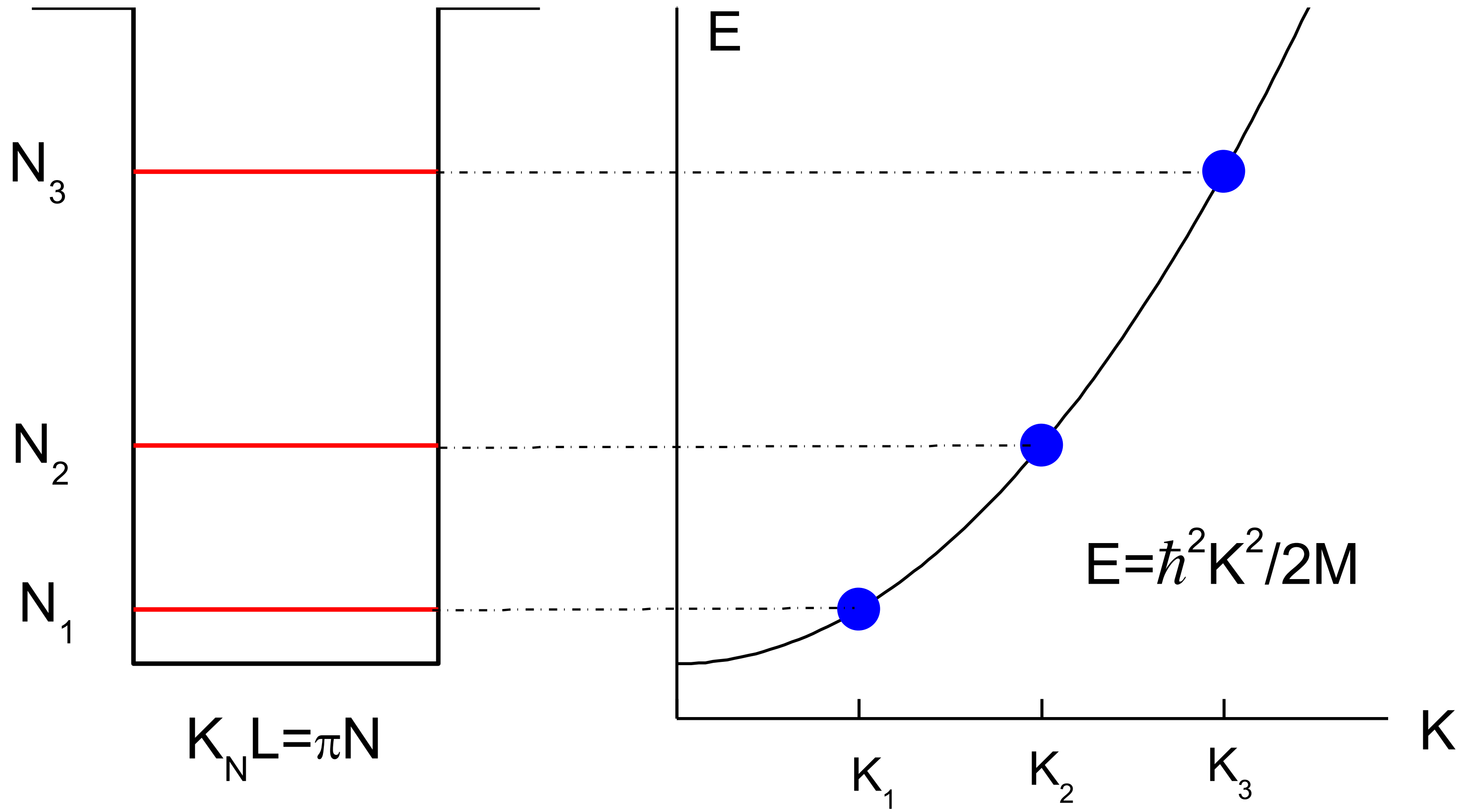
Experimental observations

GaAs, **CdTe, ZnTe** and **ZnSe QW**.QW width 50 – 1000 nm; exciton Bohr radius from 3nm to 12 nm,



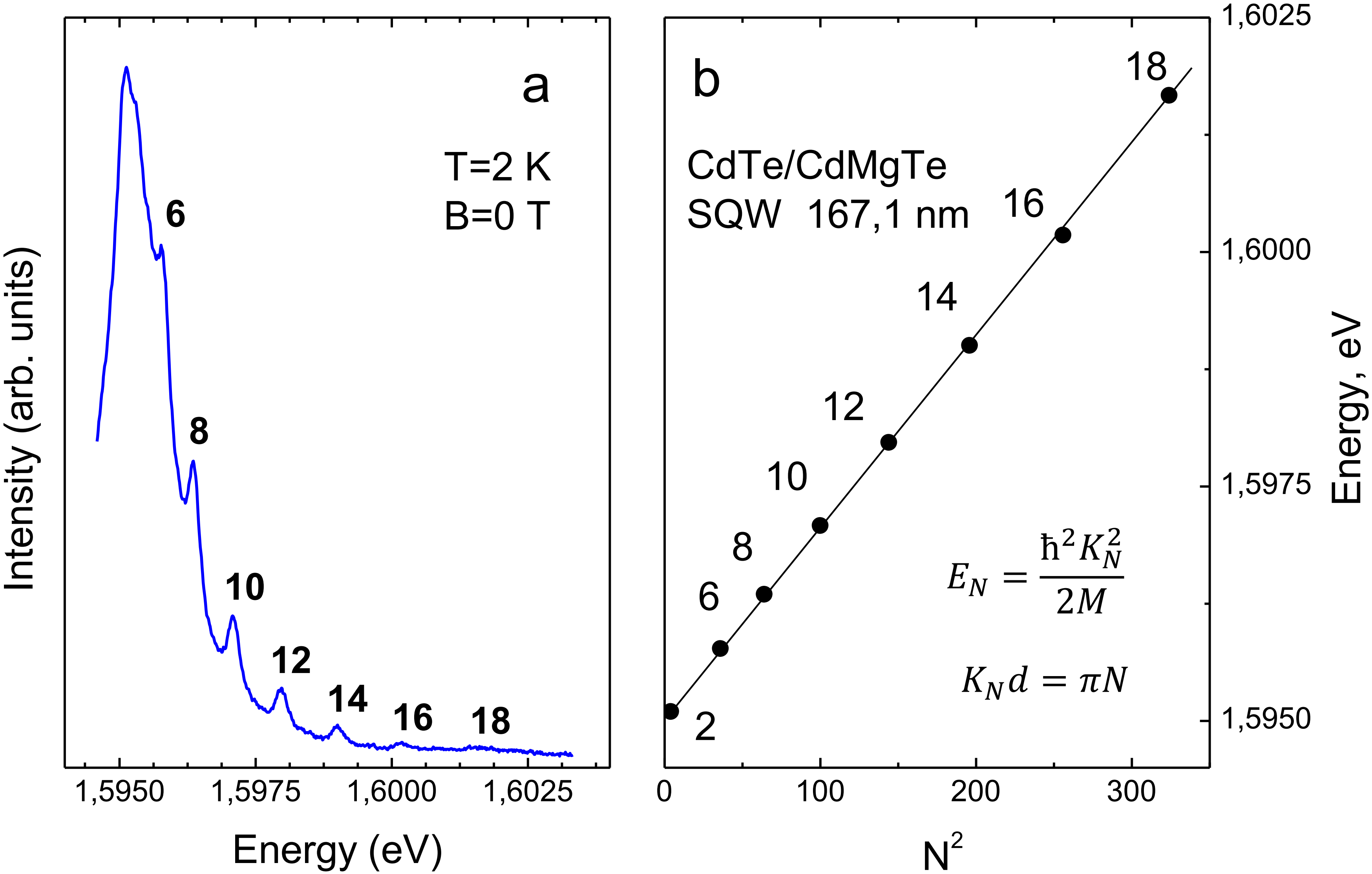
Samples with wide QW

Exciton center of mass quantization

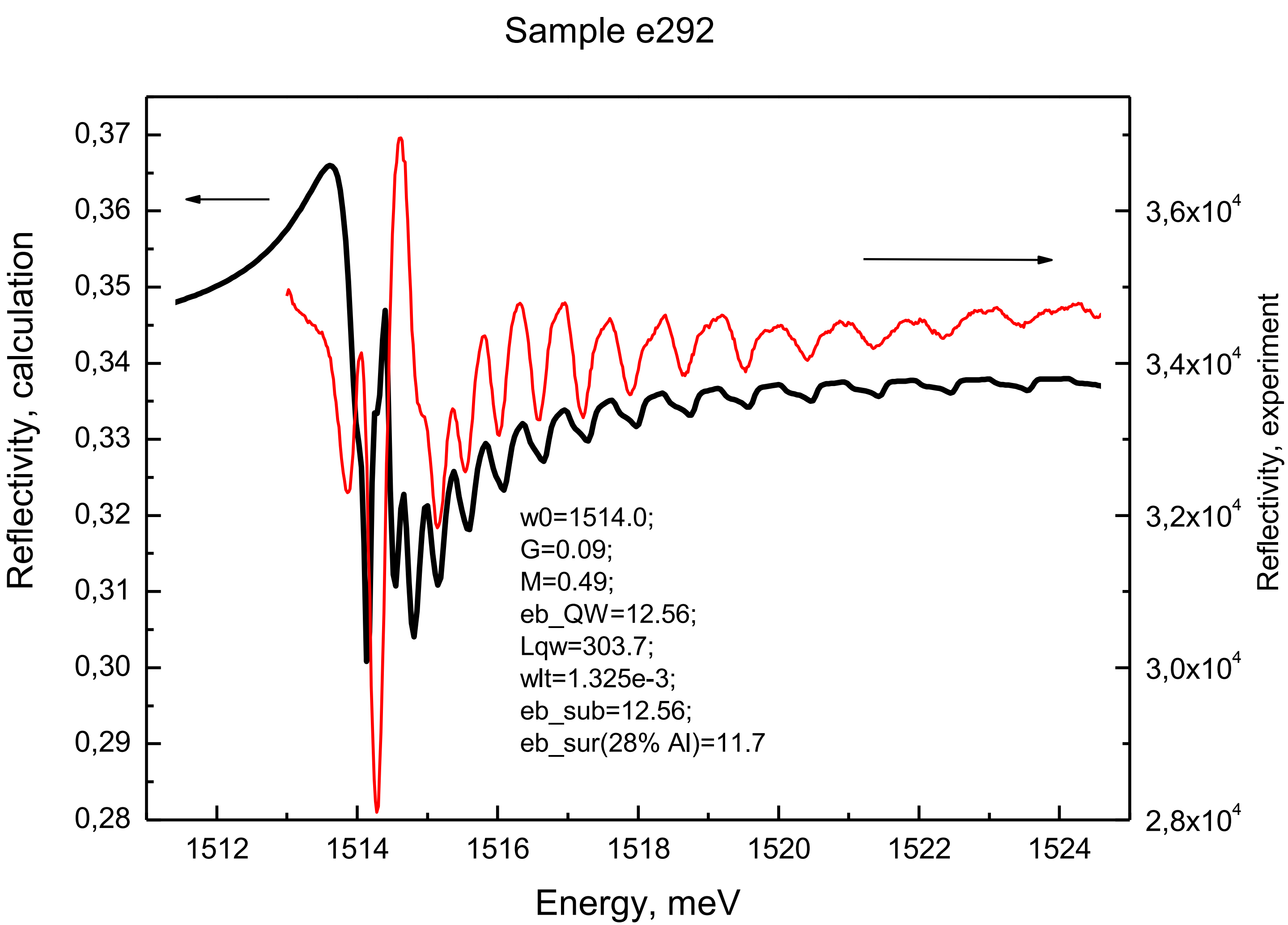


The exciton safe its bulk properties but in the spectrum we have referent points

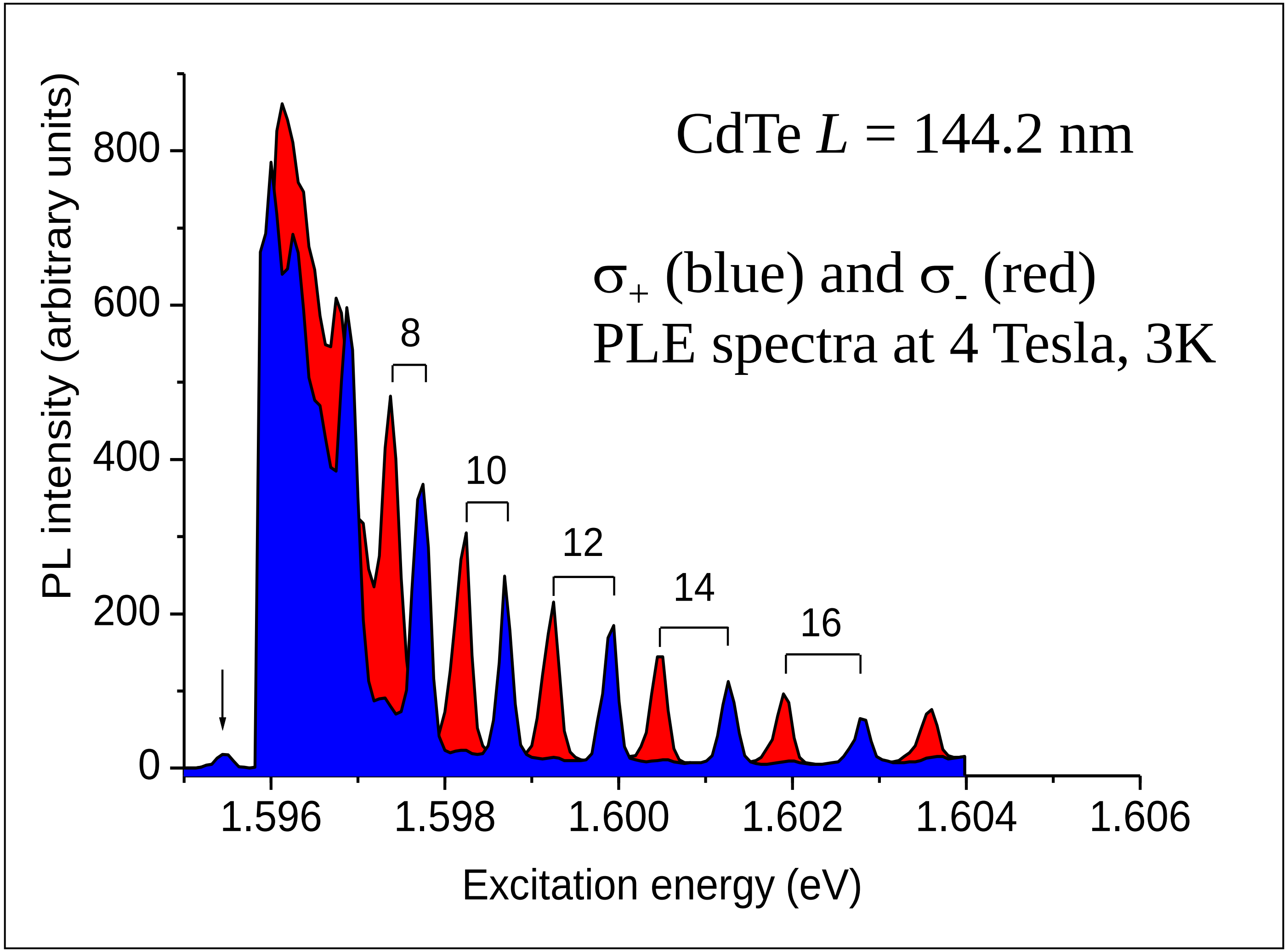
Center of mass quantization in PL spectra



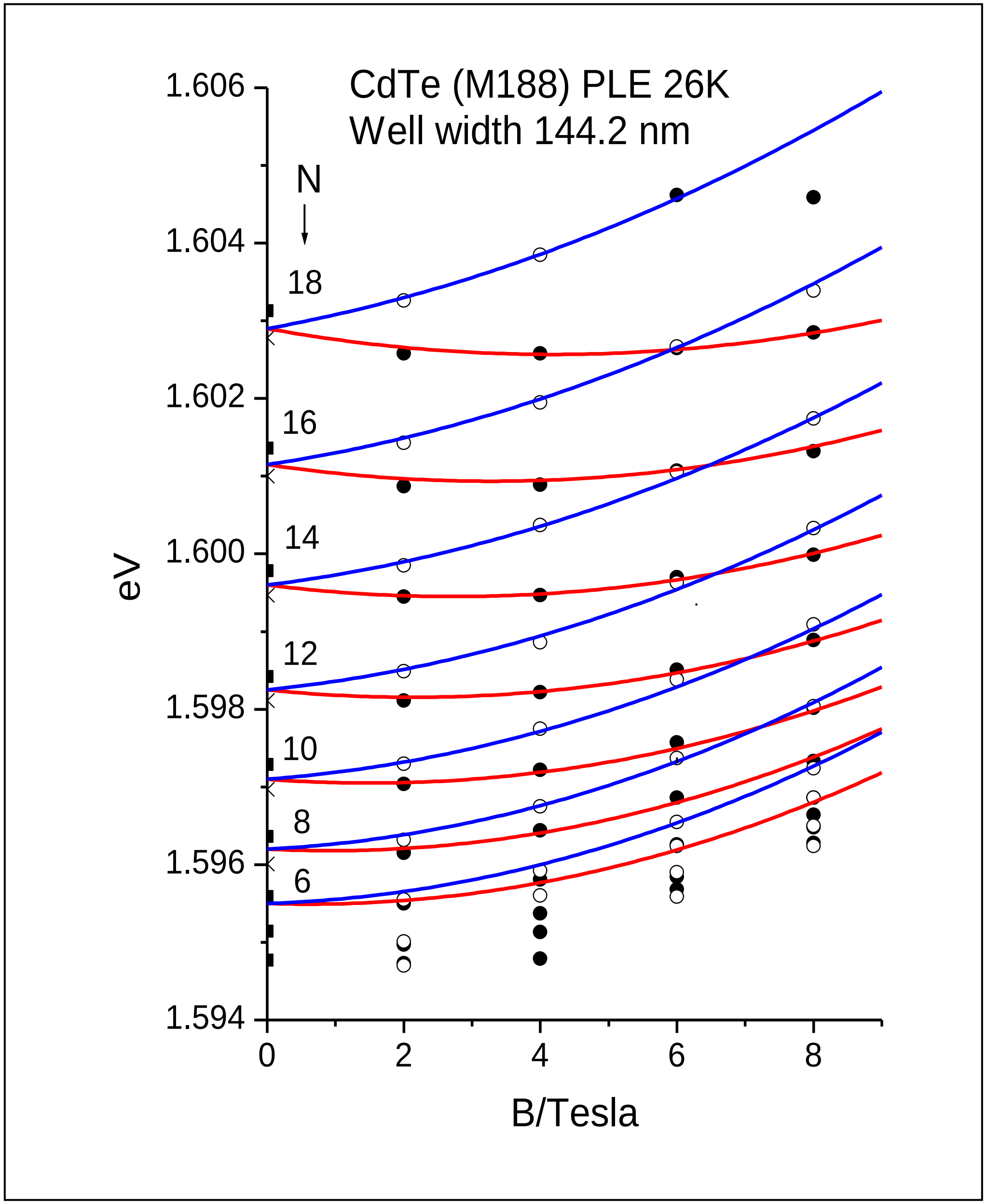
Center of mass quantization in reflectivity



PLE in magnetic field of 4T

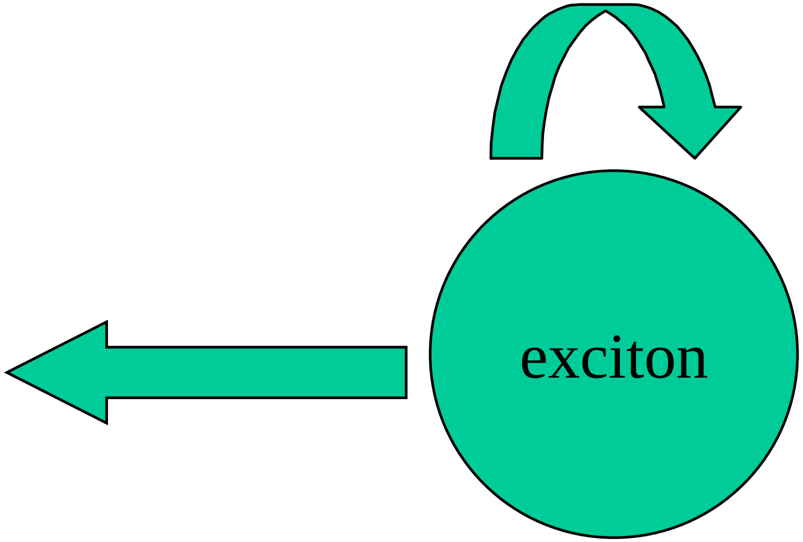


Zeeman splitting of the exciton states



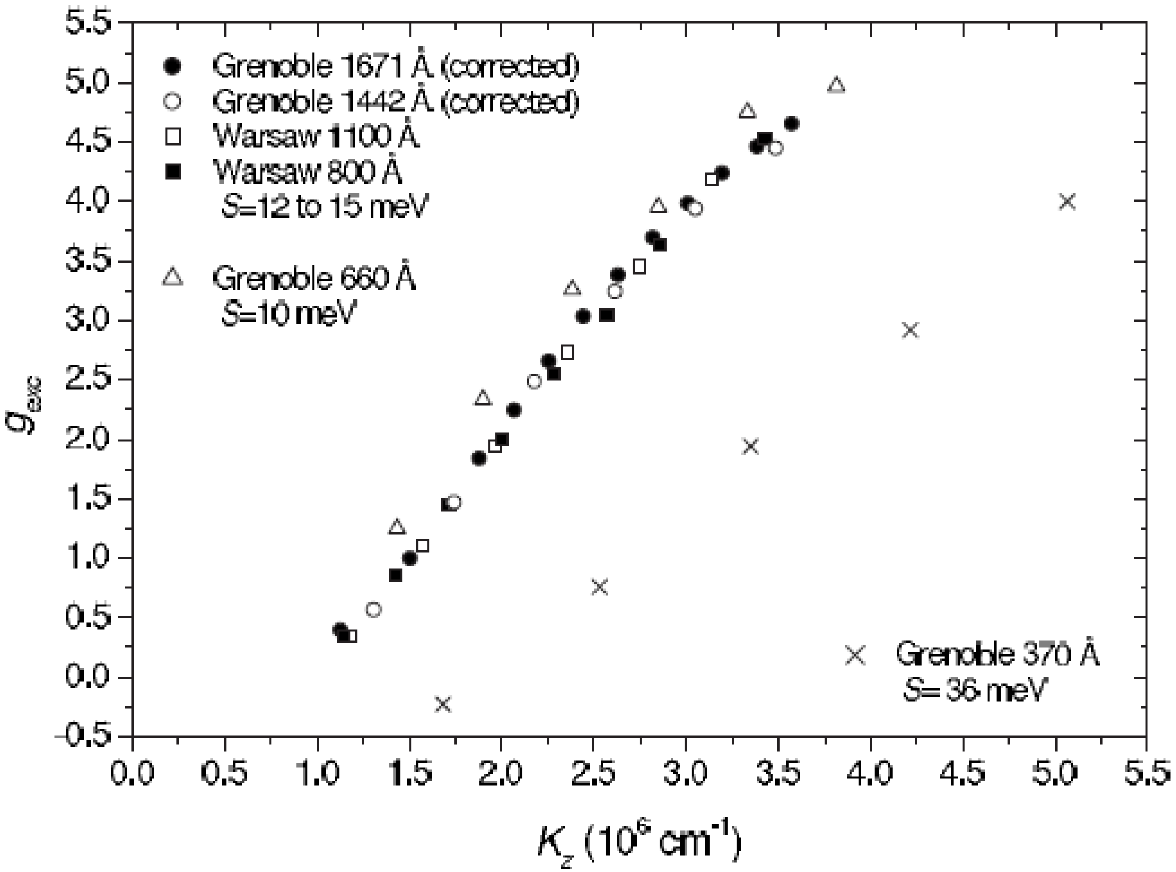
Increase of magnetic momentum at exciton motion

Exciton magnetic momentum $\boldsymbol{\mu_B g}$ increases proportional to its kinetic energy

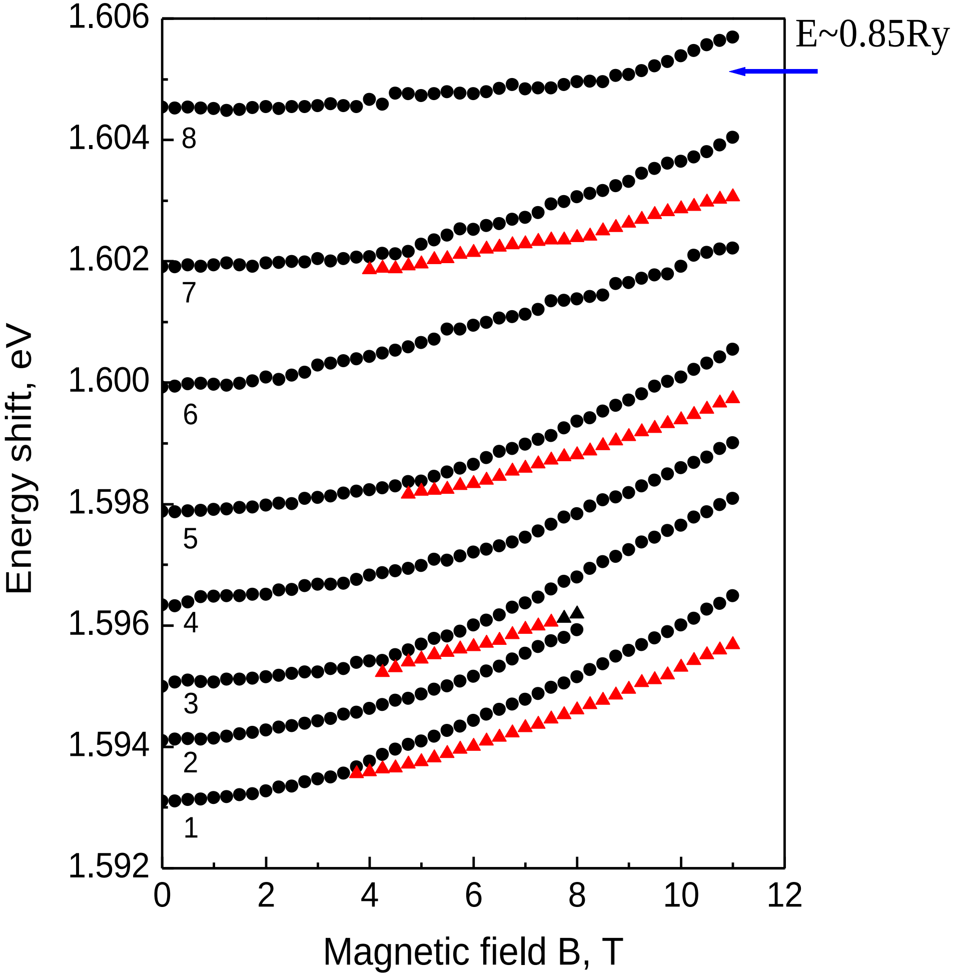


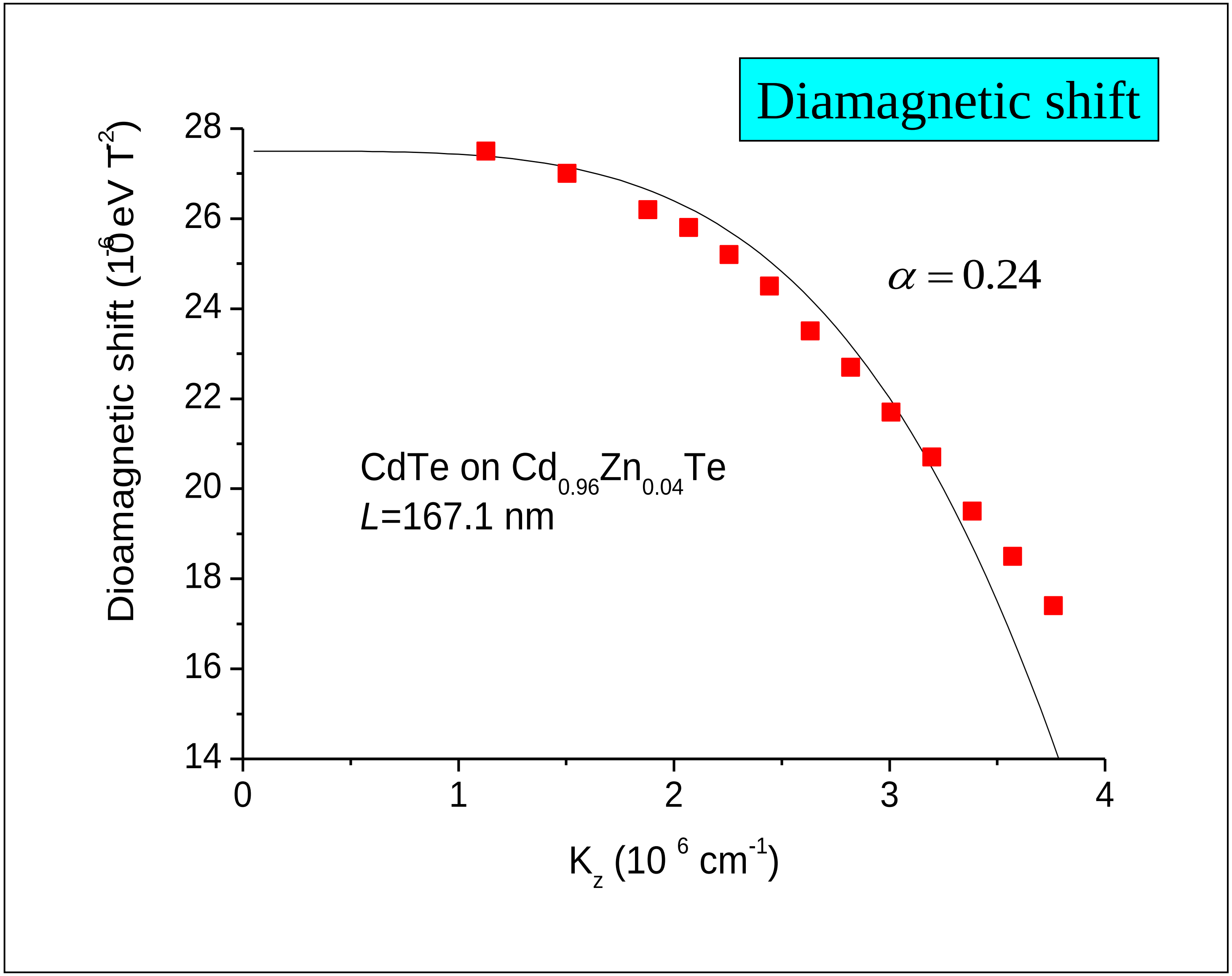
This is a result of mixing of *1S* exciton ground state and excited n*P* states of internal motion. Orbital momentum from *P* states “transfer” to *S* state.

The value of the K^2H corrections to the Zeeman splitting depends on the heavy – light hole splitting



Exciton diamagnetic shift decreases with increasing of quantized level





Diamagnetic shift
$\alpha = 0.24$
CdTe on $Cd_{0.96}Zn_{0.04}Te$
L=167.1 nm
Dioamagnetic shift (10^{-6} eV T^{-2})
K_z (10^{6} cm^{-1})
28
26
24
22
20
18
16
14
0
1
2
3
4

Exciton Hamiltonian:

$$H = -\frac{\hbar^2 \vec{\nabla}_e^2}{2m_e} - \frac{\hbar^2}{2m_0}[(\gamma_1 + \frac{5}{2}\gamma)\vec{\nabla}_h^2 \mathbf{I} - 2\gamma(\vec{J}\cdot\vec{\nabla}_h)^2] - \frac{e^2}{\kappa|\vec{r}_e - \vec{r}_h|}$$

In cubic crystal it is impossible to separate exciton internal motion and center of mass motion.

In Faraday geometry:

$$\frac{\hat{\beta}\hbar\gamma}{m_0}[(\mathbf{p}_x + \frac{e}{c}A_x)J_x + (\mathbf{p}_y + \frac{e}{c}A_y)J_y](Q_z J_z)$$

Оба явления вызваны смешиванием основного *1S* состояния и возбужденных *nP* состояний внутреннего движения в экситоне

Зеемановское расщепление

$$\Delta E = 2AH(7J_z - 4J_z^3)$$

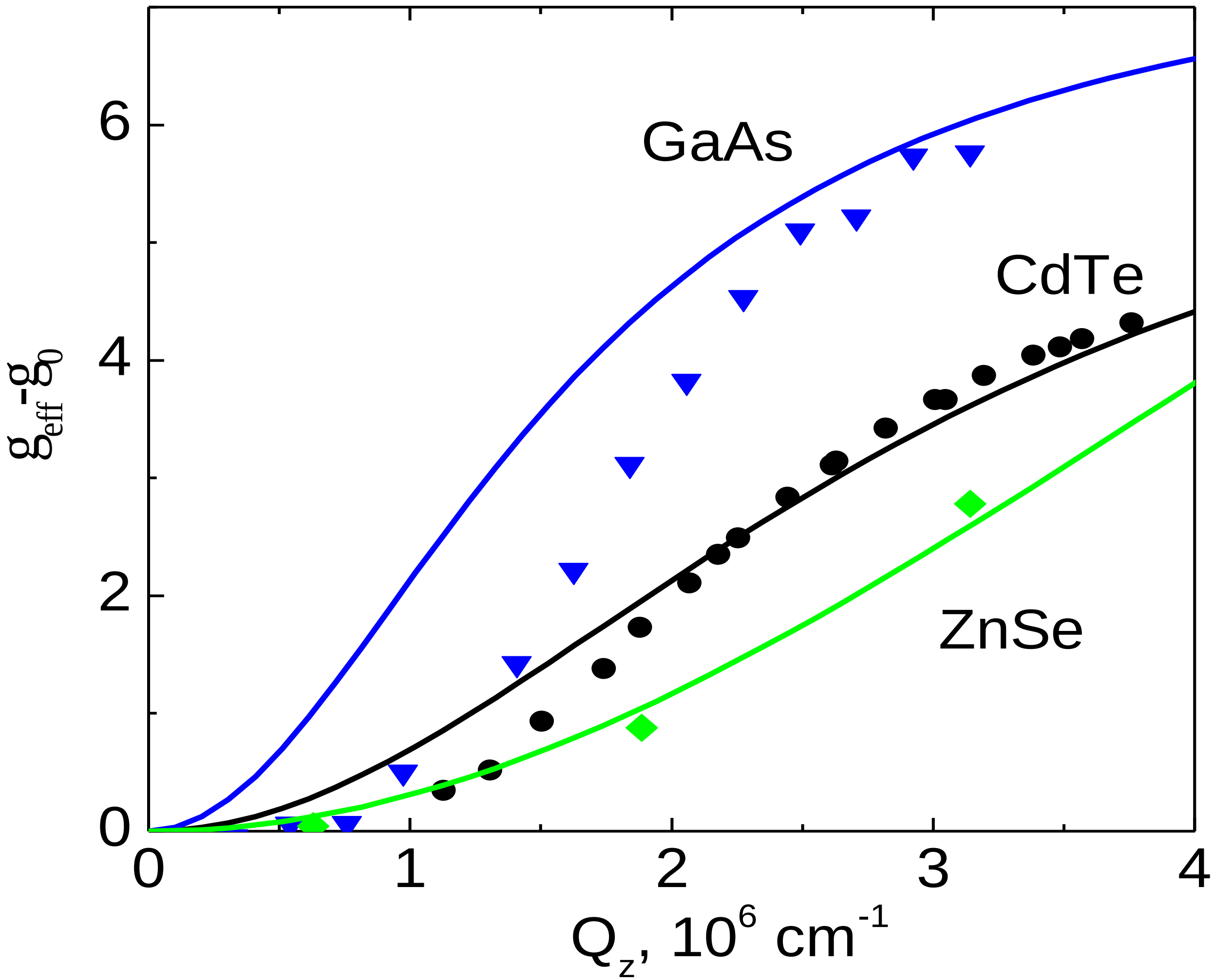
$$A = \left(\frac{\gamma}{m_0}\right)^2 \left(\frac{m_{hh}}{m_e + m_{hh}}\right)^2 \left(\frac{e\hbar}{c}\right) \left(\frac{\hbar^2}{2}\frac{Q^2}{Ry^*}\right) \sum_{n=2}^{\infty} \frac{\langle 1S | r/a_B | nP \rangle \langle 1S | a_B \nabla | nP \rangle}{1 - 1/n^2 + \Delta(Q)/Ry^*}$$

Диамагнитный сдвиг

$$\Delta E = B_0 H^2 - B_1 Q^2 H^2$$

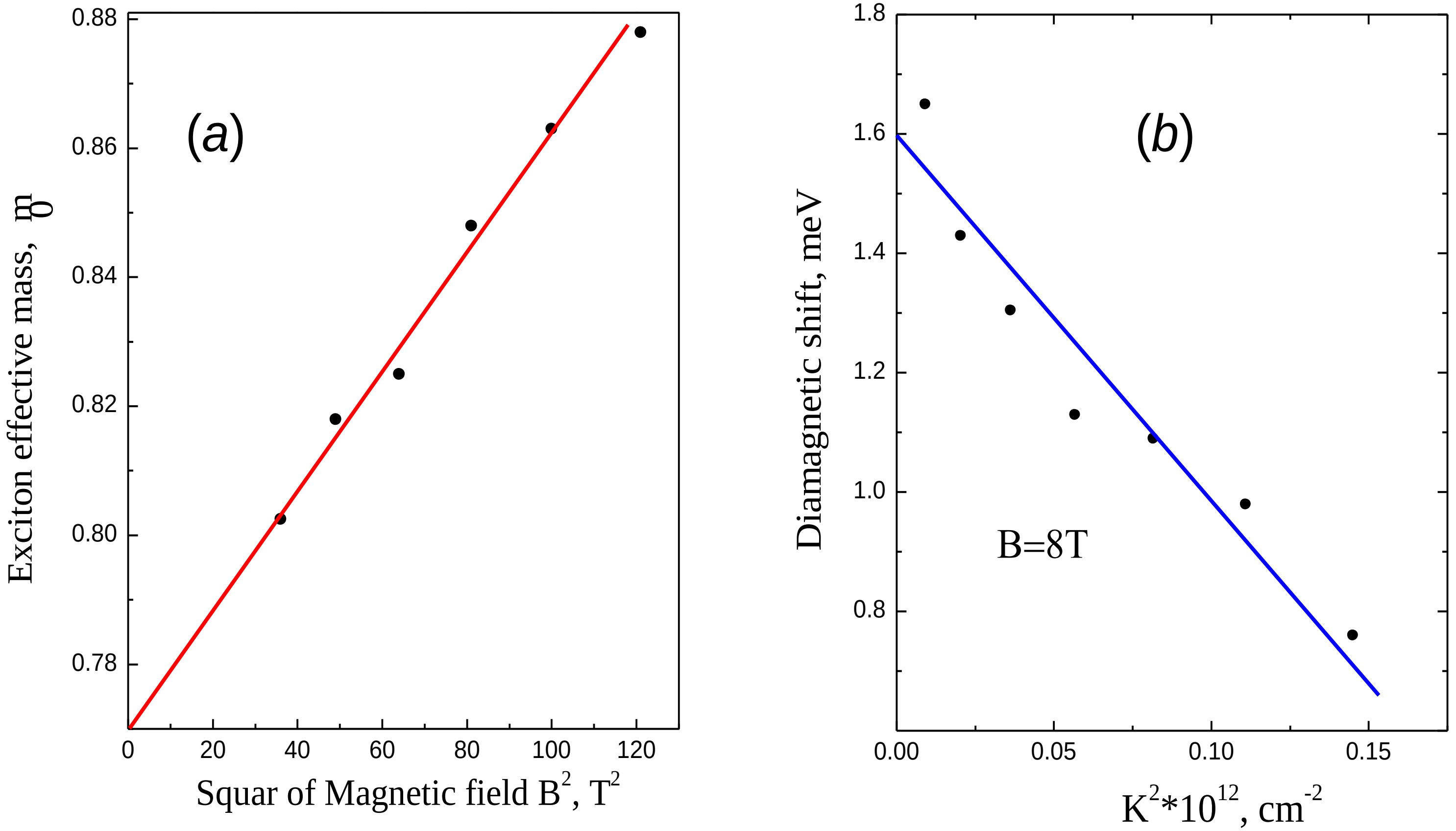
$$B_1 = \frac{3}{4}\left(\frac{\gamma}{m_0}\right)^2 \hat{\beta}^2 \left(\frac{e\hbar}{c}\right)^2 \left(\frac{1}{Ry^*}\right) a_B^2 \sum_n \frac{\left| \langle 1S | r/a_B | nP_y \rangle \right|^2}{1 - 1/n^2 + \Delta(Q)/Ry^*}$$

Exciton g-factor as a function of center of mass wave vector

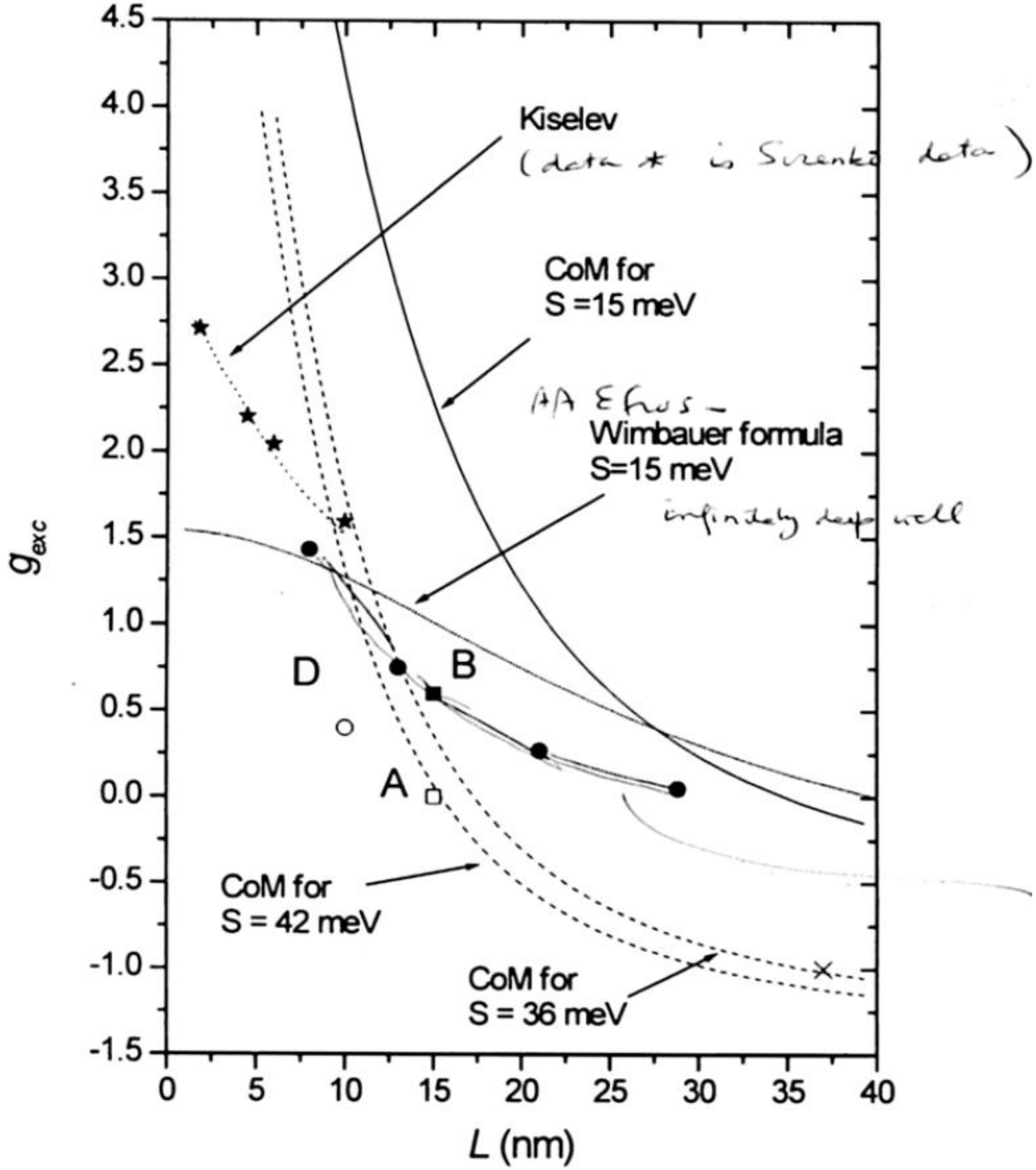


Suppression of diamagnetic shift

$$\frac{\hbar^2 Q^2}{2M} + D_0 H^2 - D_1 Q^2 H^2$$



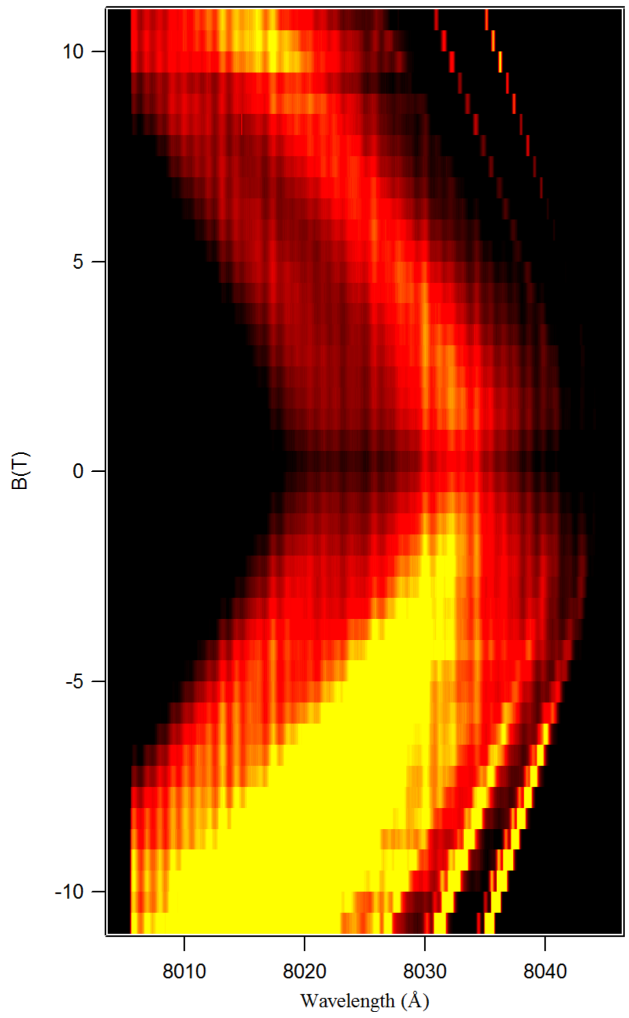
The effect of g-factor increasing can be observed not only for exciton center of mass motion but also for excitons in quantum wells and and even for free hole.



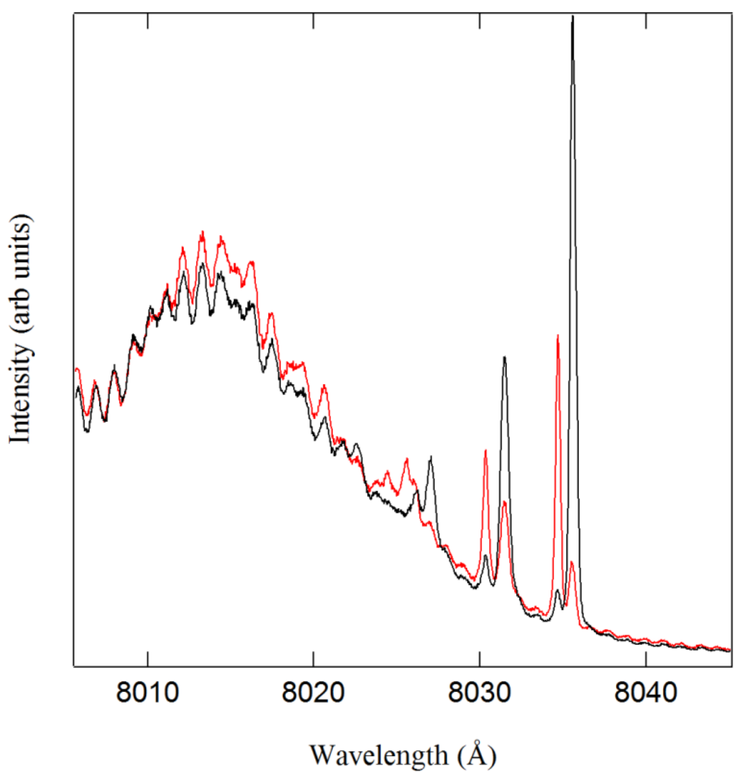
Kiselev
(data ★ is Sirenko data)
CoM for
S =15 meV
AA Efros -
Wimbauer formula
S=15 meV
infinitely deep well
D
B
A
CoM for
S = 42 meV
CoM for
S = 36 meV
g_{exc}
L (nm)

For the lateral polariton quantization one can find similar effect

Γ_4	$\{K_x K_y\} H_y + \{K_x K_z\} H_z$ $\{K_y K_z\} H_z + \{K_x K_y\} H_x$ $\{K_z K_x\} H_x + \{K_z K_y\} H_y$



B=11T



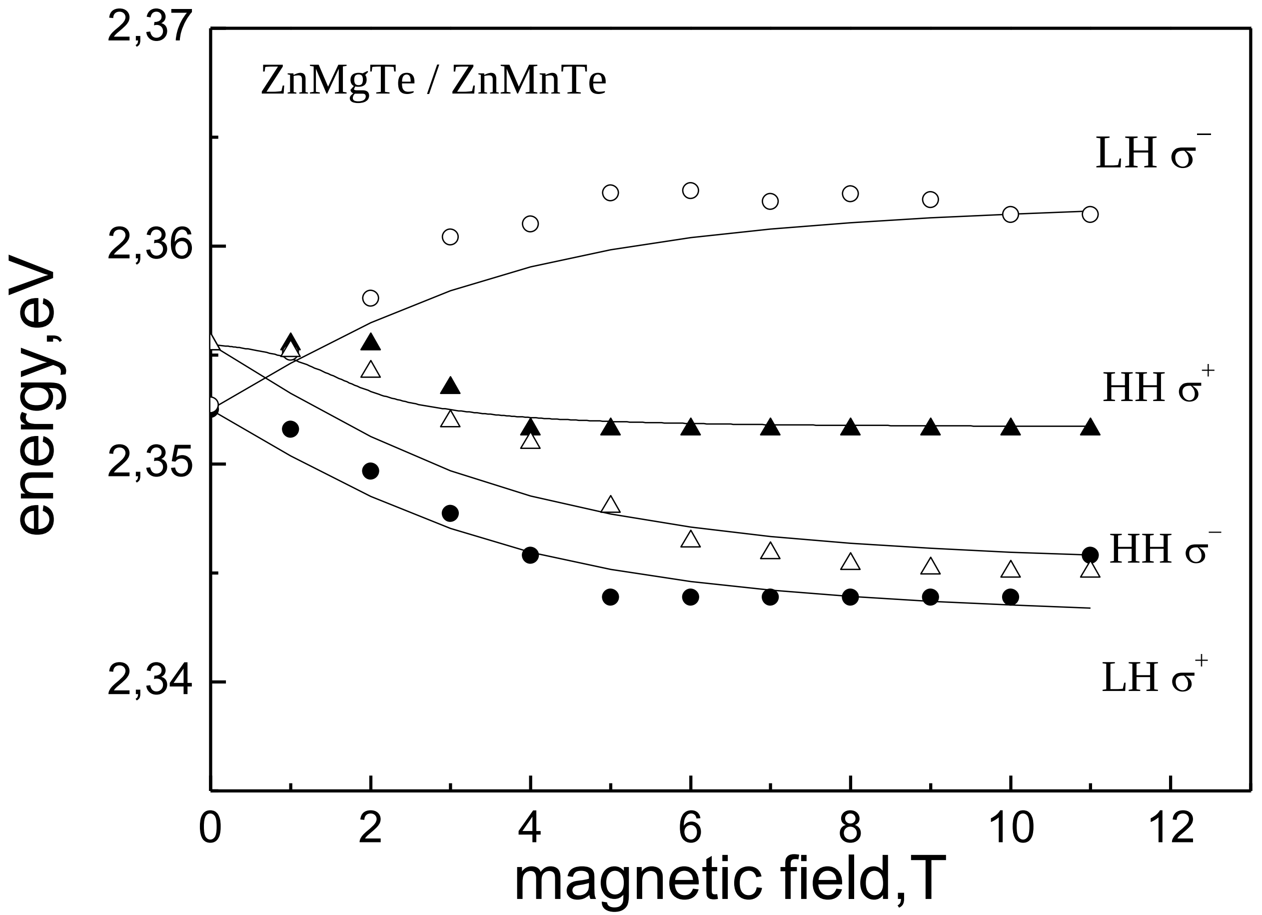
Zeeman split polariton modes

Exciton g-factor can depends also on the environment

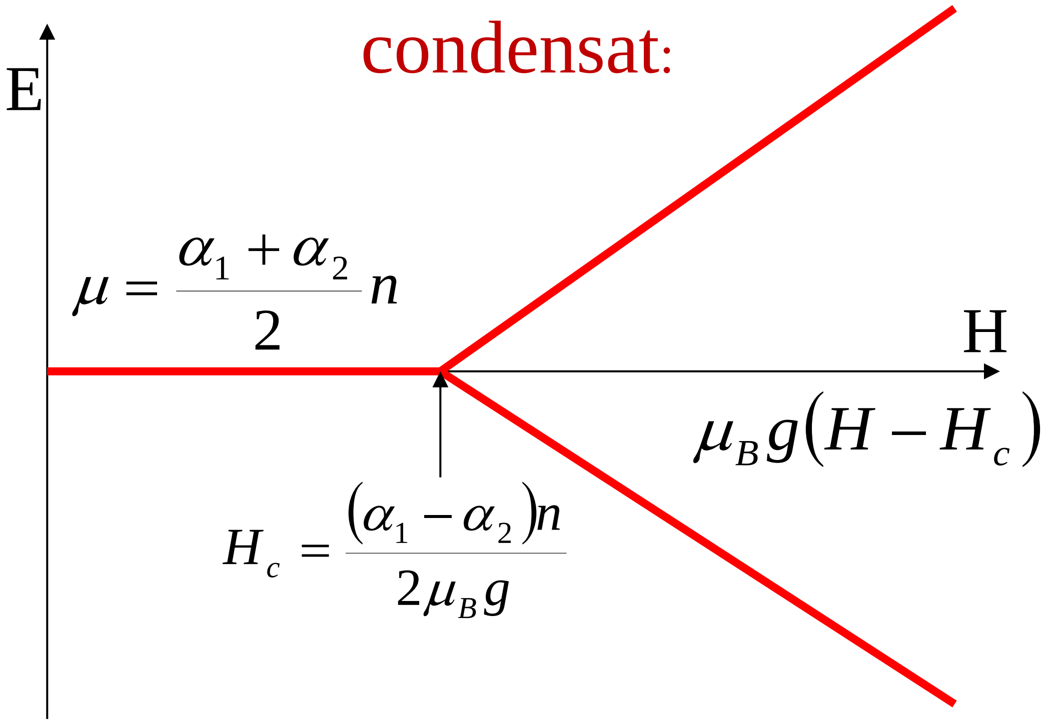
1. Giant Zeeman splitting for Excitons in semimagnetic

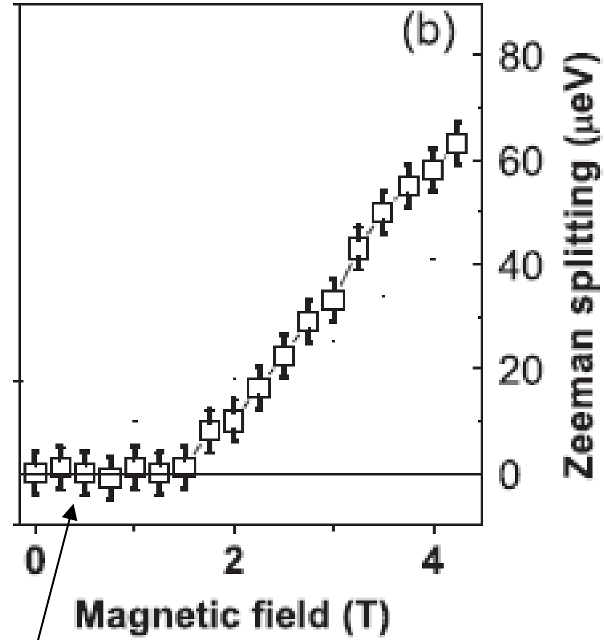
2. Zero Zeeman splitting in Bose condensate

Giant g-factor in semimagnetic semiconductor



Zero g-factor in polariton condensat:





Spin Meysner effect

$$F = -\mu n - \mu_B g B S_z + \frac{1}{2}(\alpha_1 + \alpha_2) n^2 + (\alpha_1 - \alpha_2) S_z^2$$

Y.G.Rubo, A.V.Kavokin, I.A. Shelykh, Phys.Lett. A 358, 227 (2006).

A.V. Larionov, V.D. Kulakovskii et al, Phys. Rev. Lett., 105, 256401 (2010).

Conclusion

Thank you for the attention