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SMR.769 - 16

WORKSHOP ON "NON-LINEAR ELECTROMAGNETIC INTERACTIONS IN SEMICONDUCTORS"

1 - 10 AUGUST 1994

"Magneto-optics under high optical excitation"

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These are preliminary lecture notes, intended only for distribution to participants

Magneto-Optics
under High Excitation Intensities

Outline

1. Highly excited semiconductors. (B=0)
   Basic Experimental Results
   and Theoretical Concepts

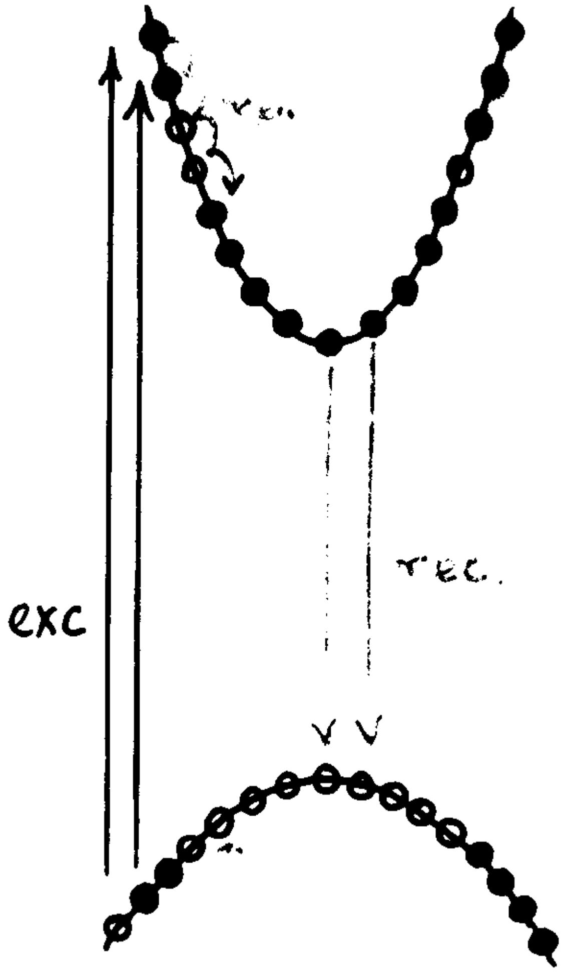
   - high density electron-hole systems
     - electron-hole Liquid
     - electron-hole plasma
   - changes in the energy structure due to presence of free carriers

2. Studies of thin semiconductor layers in magnetic fields
   - motivations and interband magneto-optics at low excitation intensities

   * Highly Excited GaAs/GaAlAs QWs
     - system studied and experiments
     - early experimental results
     - tentative explanation
       interaction between 2D magnetoexcitons
     - time-resolved (1 nsec) data
       at very high fields
     - interpretation(s) ?

3. Conclusions

Gas of electron-hole pairs
Quasi - stationary population under (intense) optical excitation



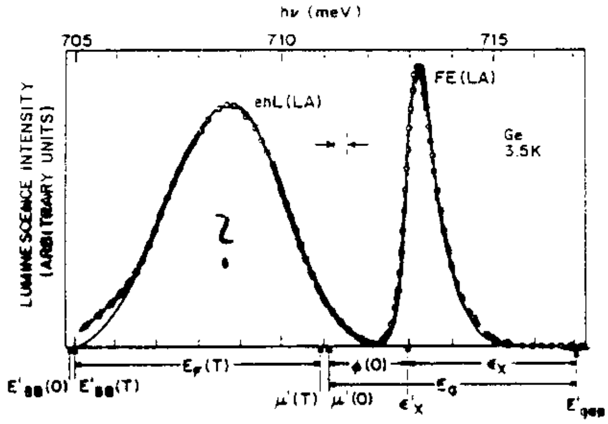
$$\tau_{exc}^{pulse} > \tau_{rec} > \tau_{rel}$$

Experiments

Luminescence vs. excitation power "below-band-gap" emission

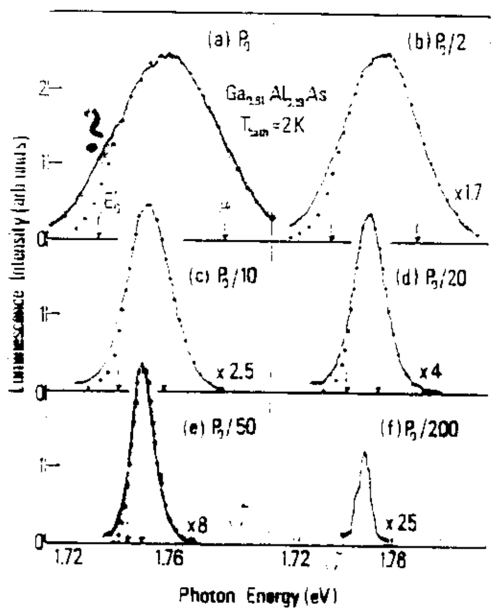
Ge →

electron-hole Liquid

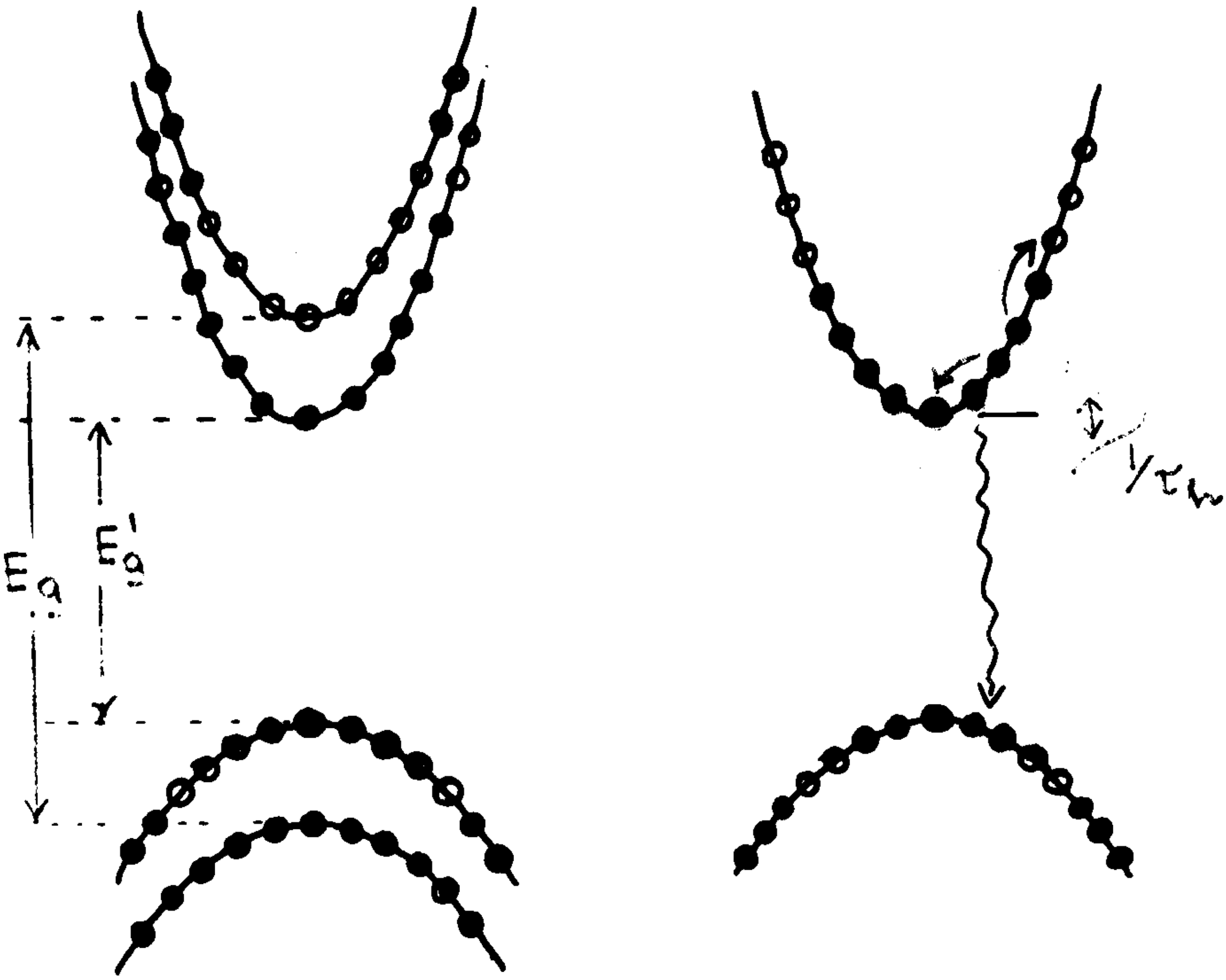


direct s.c. →

[illegible] density saturated electron - hole plasma



Understanding in terms of:



bandgap renormalization + **spectral broadening**

$\Delta E_g \sim r_s^{-2/3}$

$\sim$ 40 meV for $n_{eh} = 10^{12}\,cm^{-2}$

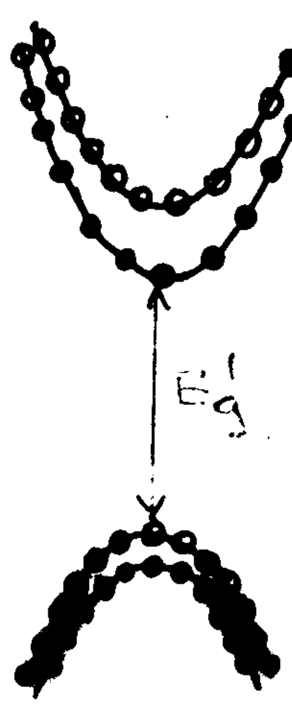
$1/\tau_h \sim |E - E_F|$

3.2

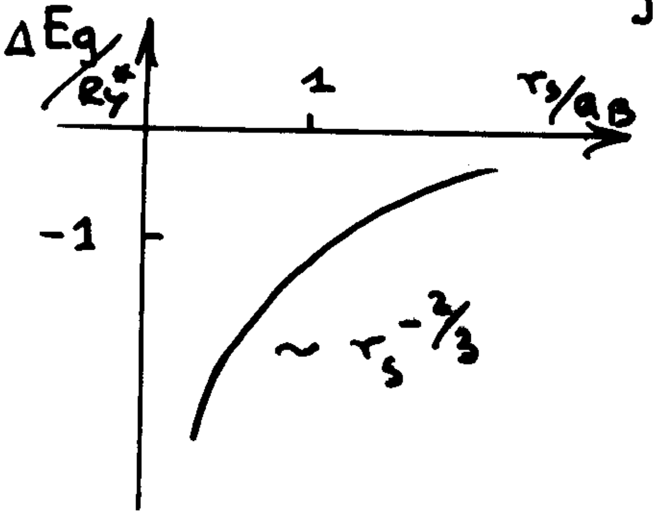
Electron - hole system

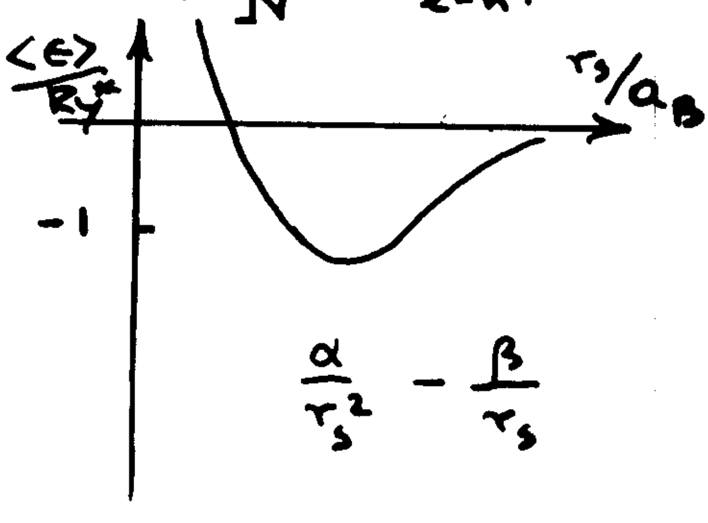
$$H = -\sum_i \frac{\hbar^2 \nabla_i^2}{2m_e} - \sum_j \frac{\hbar^2 \nabla_j^2}{2m_h} - \sum_{i,j} \frac{e^2}{\varkappa |\vec{r}_i^{\,e} - \vec{r}_j^{\,h}|}$$

$$+ \frac{1}{2} \sum_{i \neq j} \frac{e^2}{\varkappa |\vec{r}_i^{\,e} - \vec{r}_j^{\,e}|} + \frac{1}{2} \sum_{i \neq j} \frac{e^2}{\varkappa |\vec{r}_i^{\,h} - \vec{r}_j^{\,h}|}$$

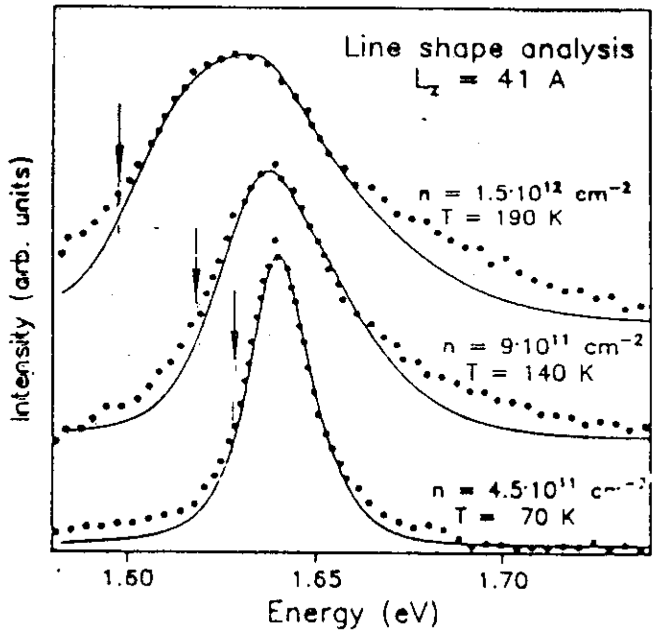


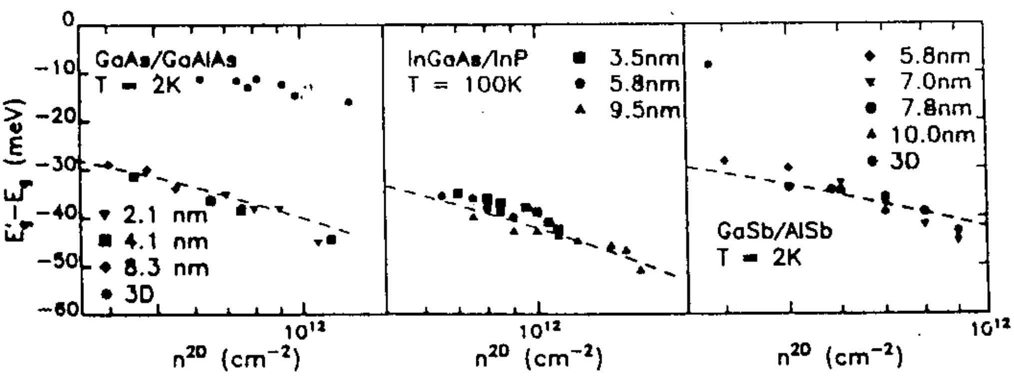
Calculations: $E_g(n_{e\text{-}h})$, $\frac{E_{TOT}}{N}(n_{e\text{-}h})$





Experiment & Theory

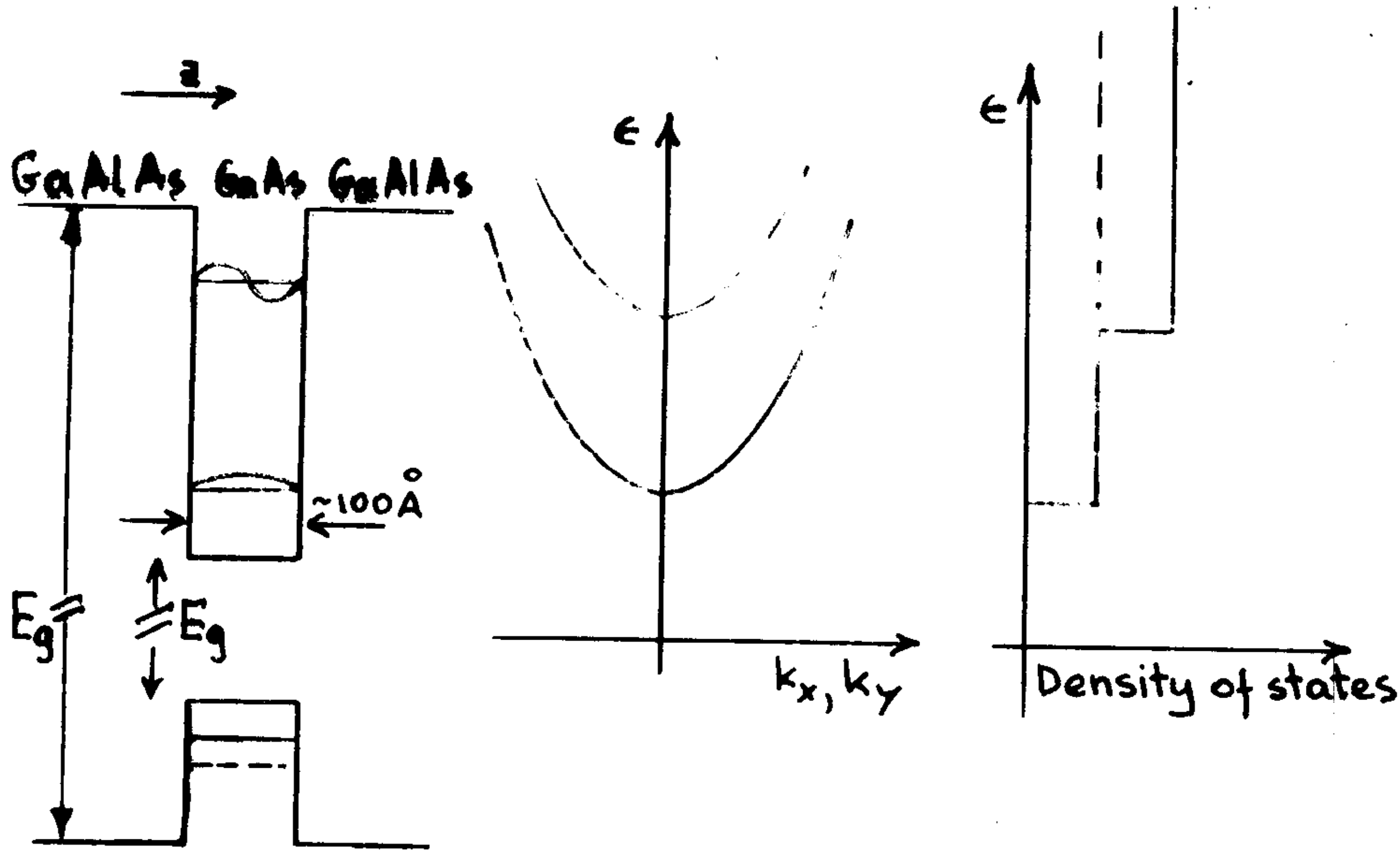


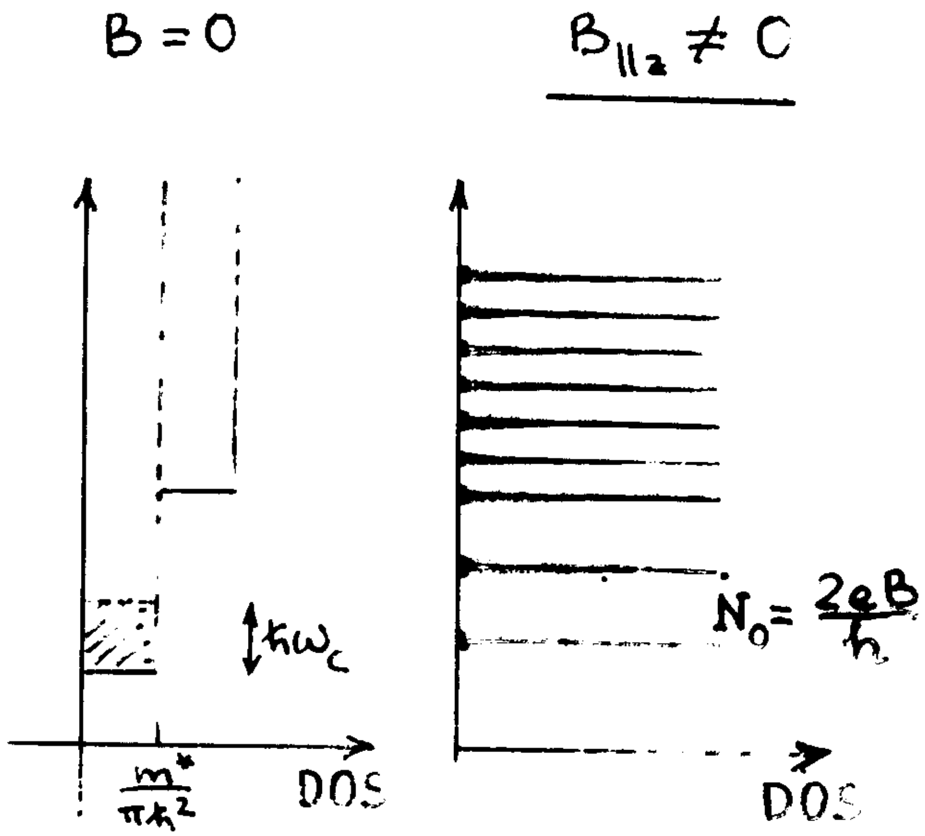


quite good agreement

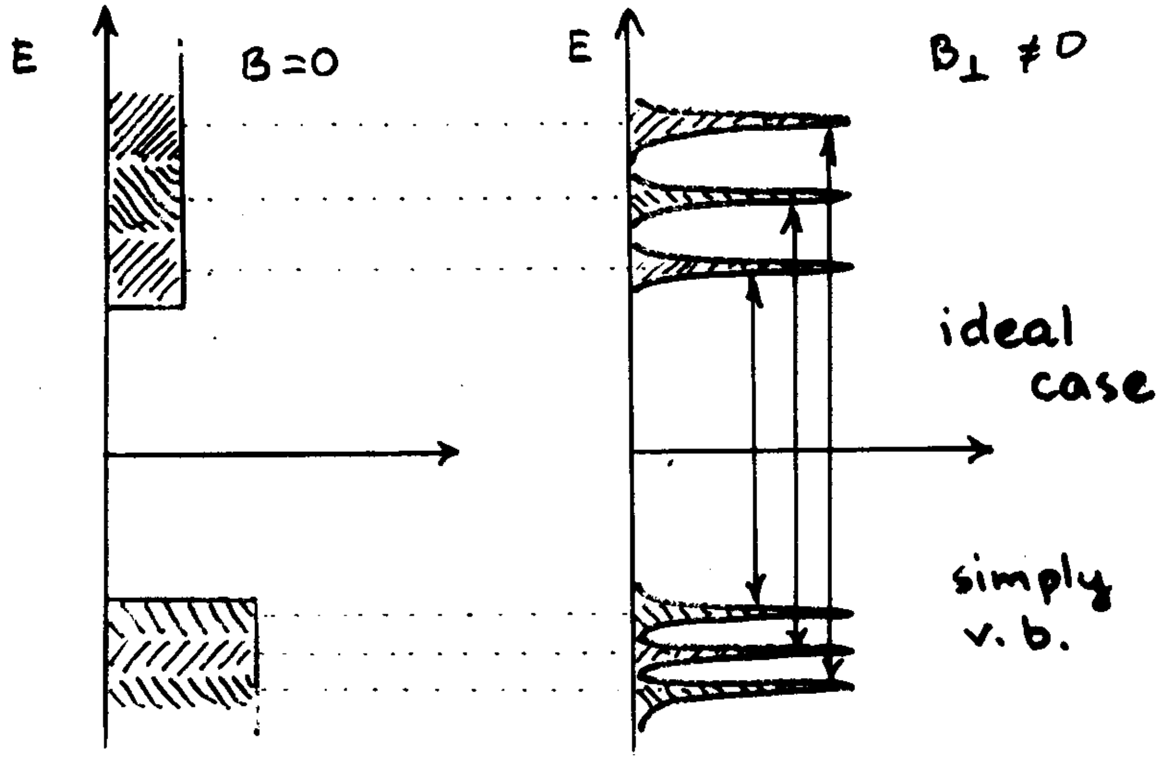
5.1

Two-Dimensional Semiconductor Structures subjected to Magnetic Fields



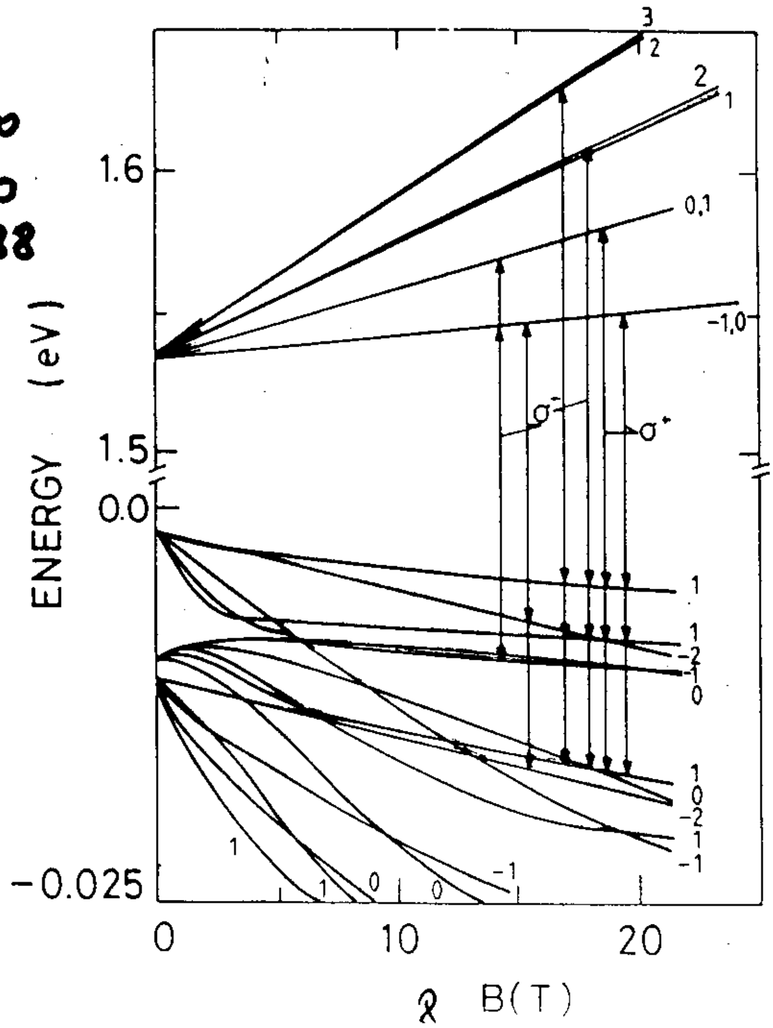


Interband Magnetooptics: Linear response



In fact much more complicated (v.b!)

Fasolino Ancilotto 1987, 1988



$+ \frac{e^2}{\chi r_{12}}$

G.E.W. Bauer 1990

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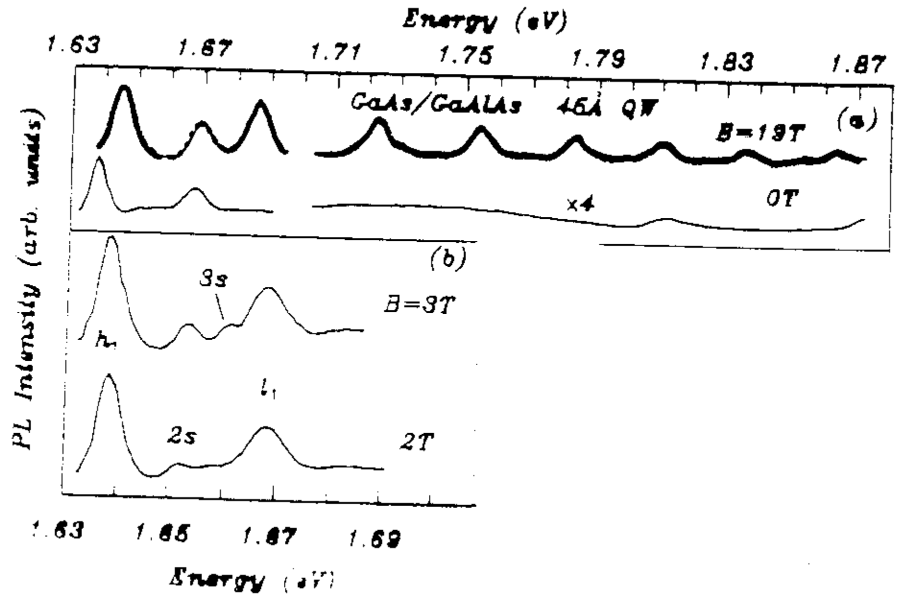
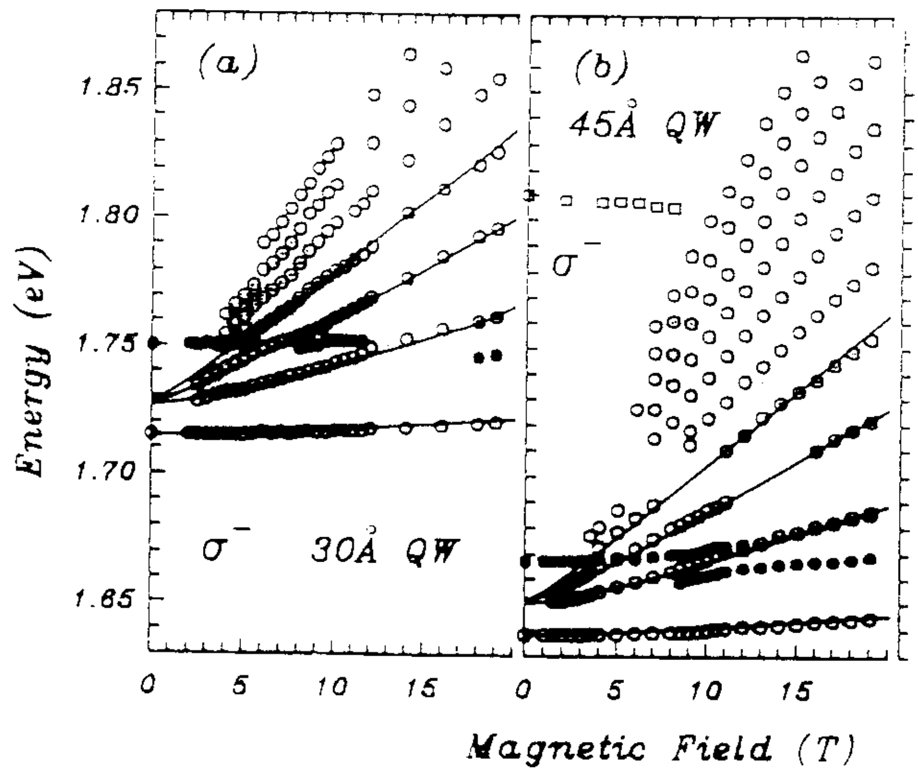
Magnetoexcitons

Narrow QWs

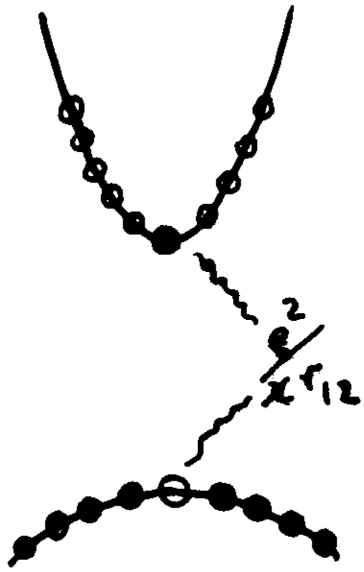




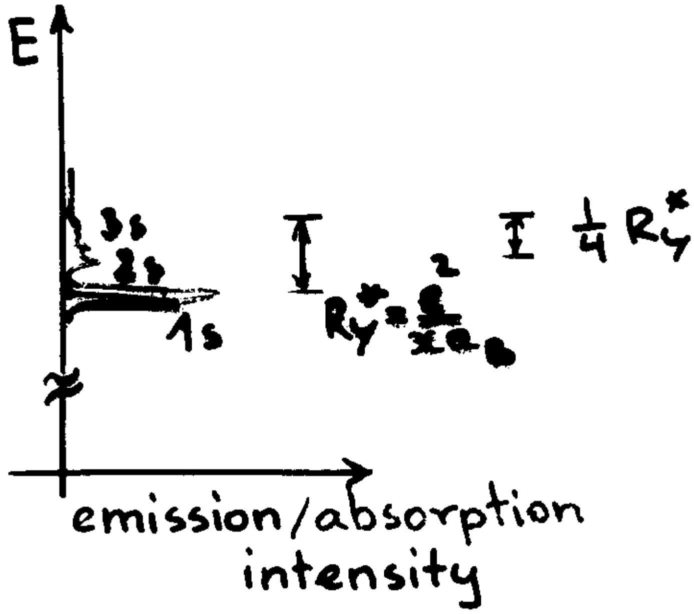
"2D Hydrogen Atom" $\hbar\omega_c > R_y^*$

in High Field Limit

Excitons

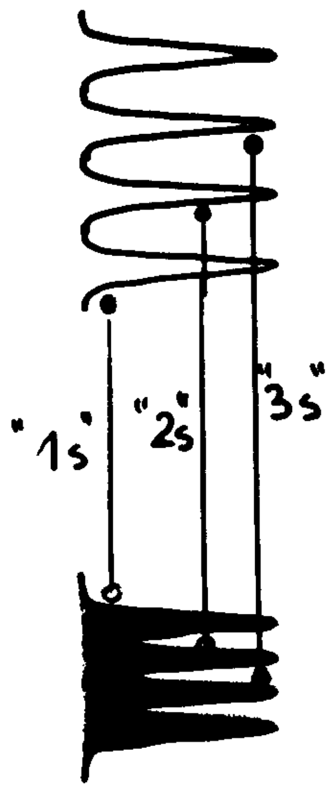


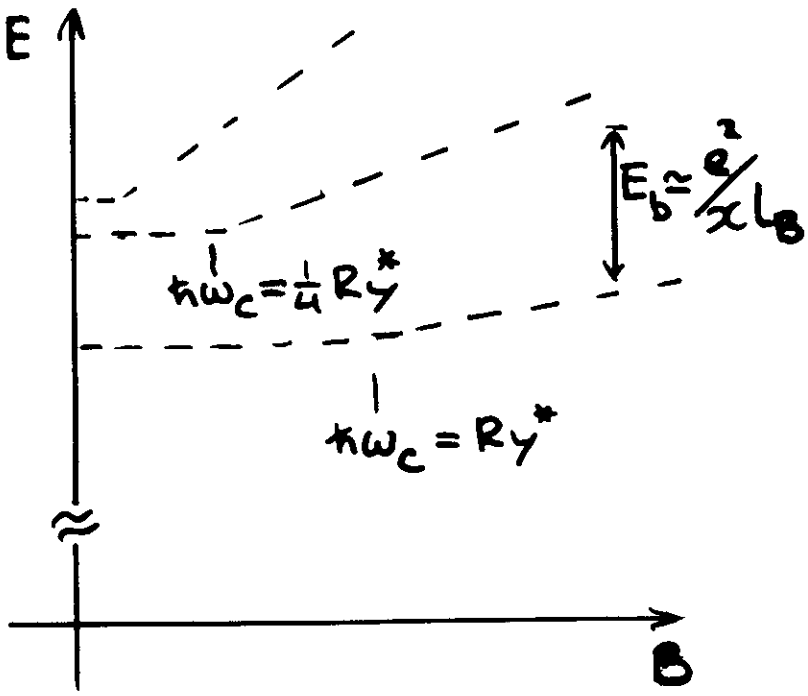
B = 0



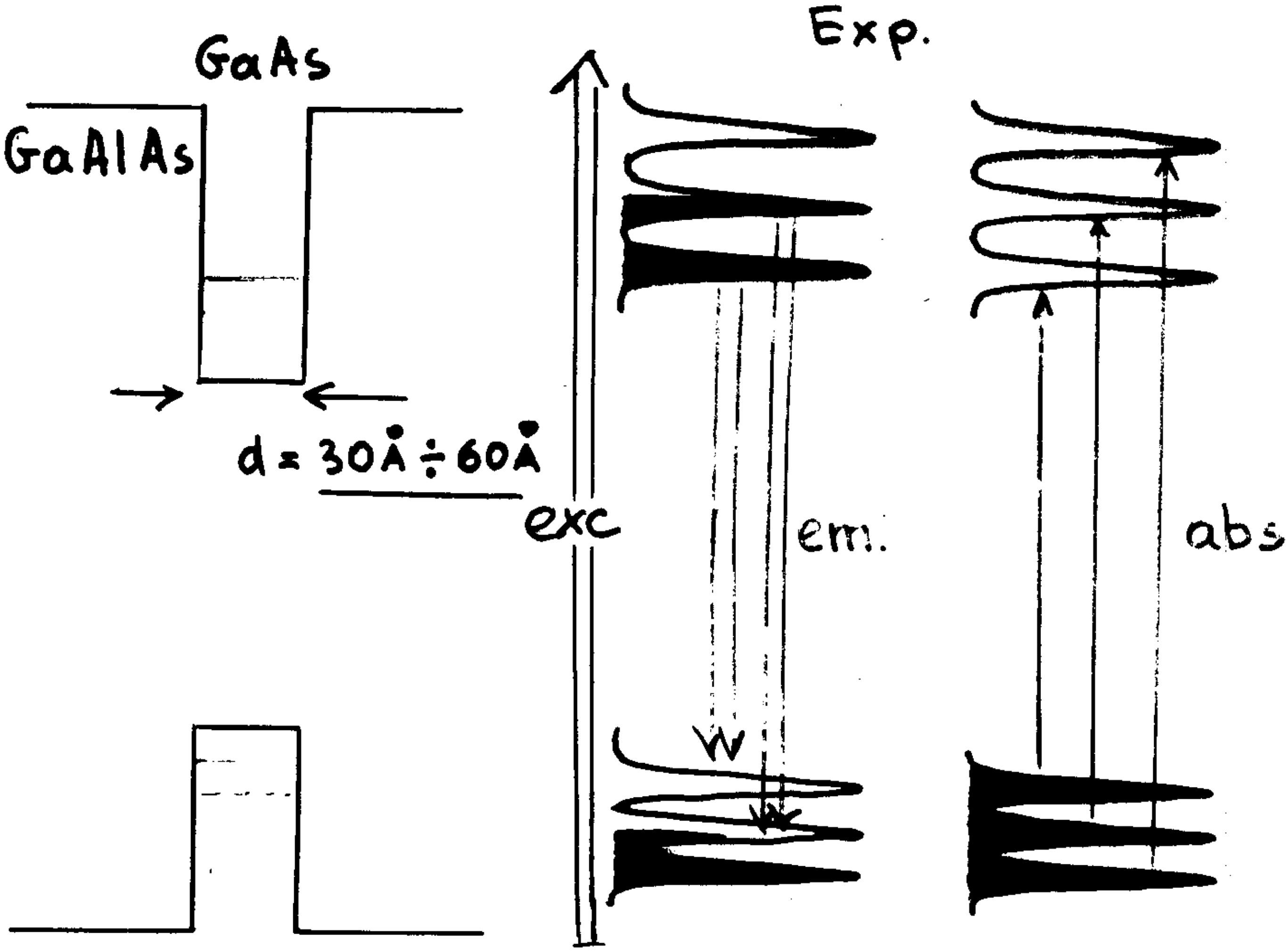
Magnetoexcitons

$\hbar\omega_c > e^2/\varkappa l_B$





Systems investigated



$\tau_p \sim 10\,ns$

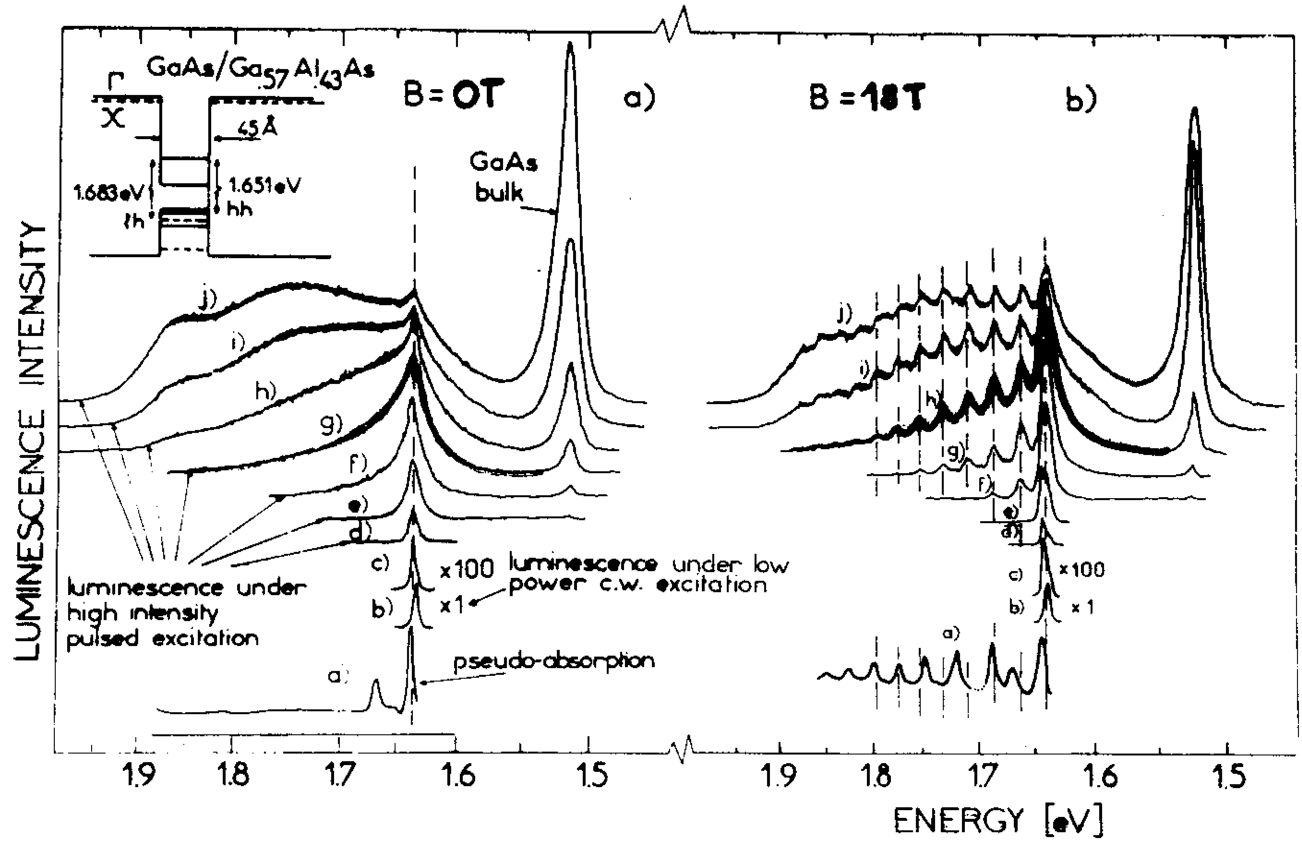
$P_d \sim 1\,MW/cm^2$

* Butov, Kulakovski
GaInAs/InP , emission spectra

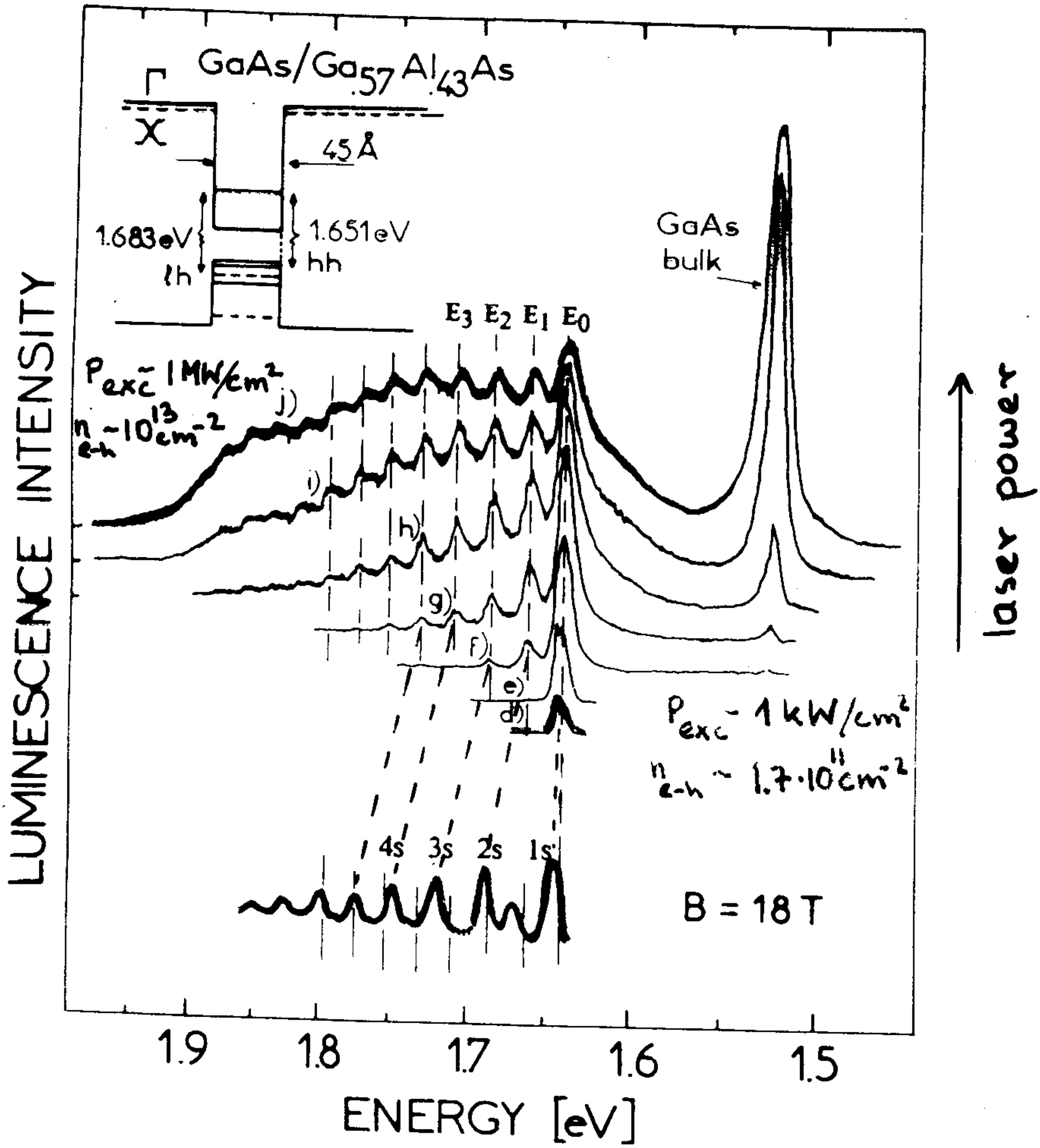
** Stark et al
GaAs/GaAlAs , pump-probe exp.
(lower excitations)

Emission under high excitation

Early experimental results



Main features of magneto-luminescence spectra



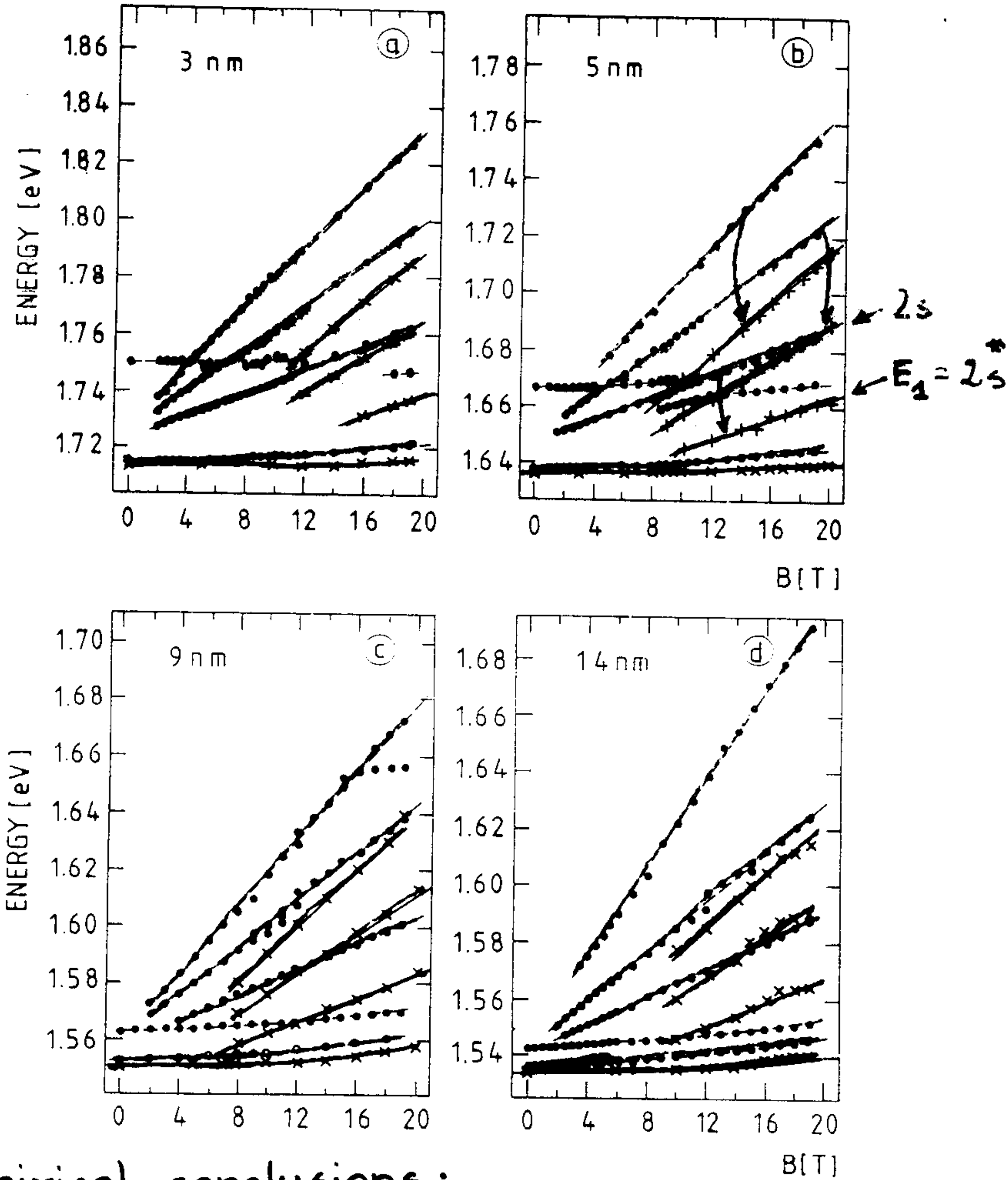
* redshift of emission peaks with respect to absorption transitions

** almost no shift of emission peaks vs. excitation intensity

Landau level fancharts

— emission

— absorption



Empirical conclusions:

*) "energy renormalization" $\Delta(E_1 - 2s) \sim 2E_b$

**) "reduced mass renormalization" $\frac{\Delta m}{m} \sim 20\%$

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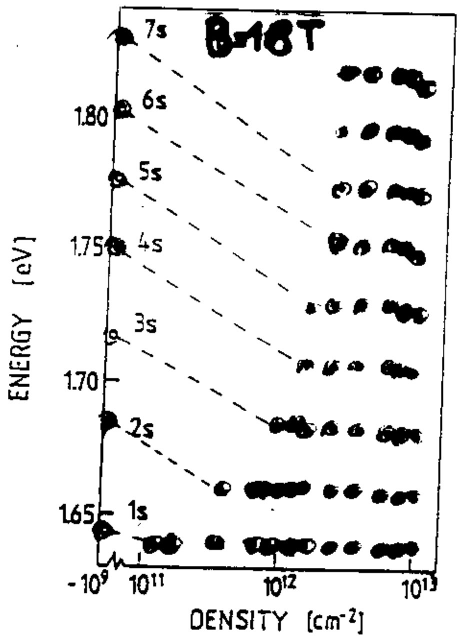
3

Energy positions of emission peaks vs. excitation intensity ? (n_{e-h})

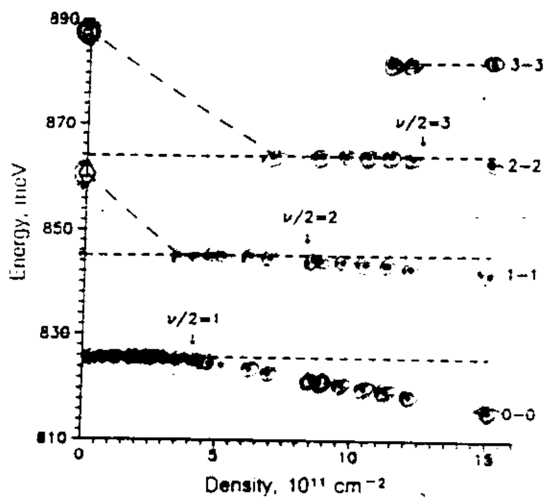
GaAs/GaAlAs



GaInAs/InP

Butov, Kulakovskii

JETP (91)

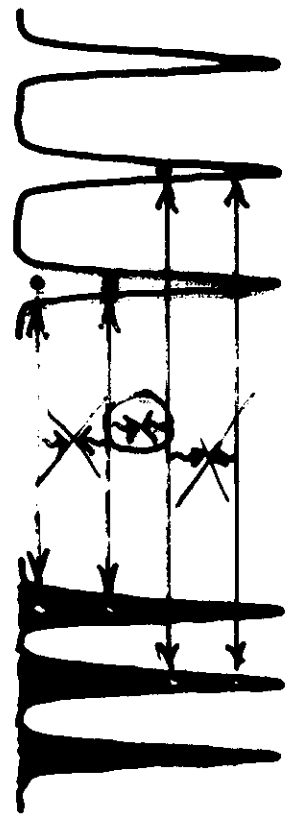


B = 8.65 T

15

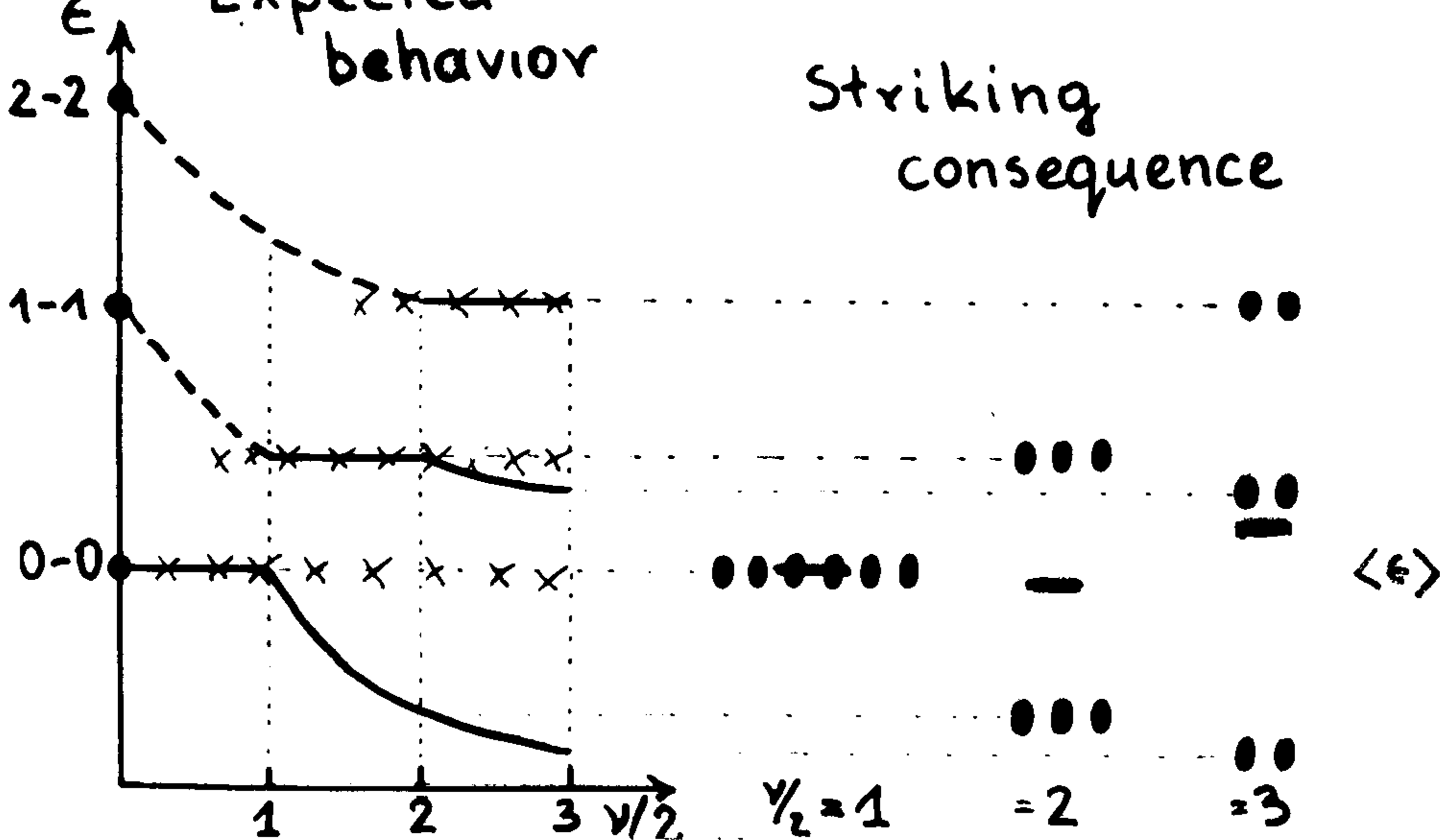
Tentative explanation
Interaction between 2D magnetoexcitons

Lerner, Lozovik JETP, 1981
Paquet, Rice, Ueda PRB, 1985
Stafford, Schmitt-Rink, Schäfer PRB, 1990
Bychkov, Rashba PRB, 1989
G. E. W. Bauer 1992

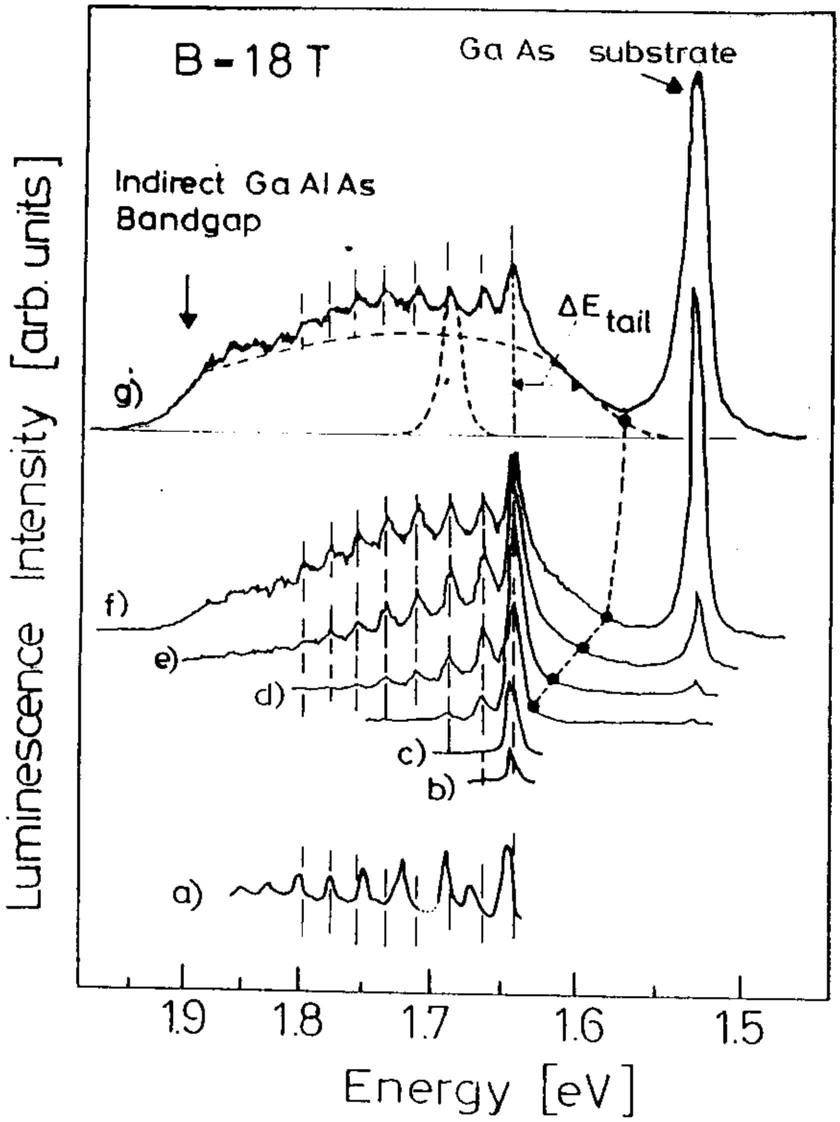


Expected behavior

Striking consequence



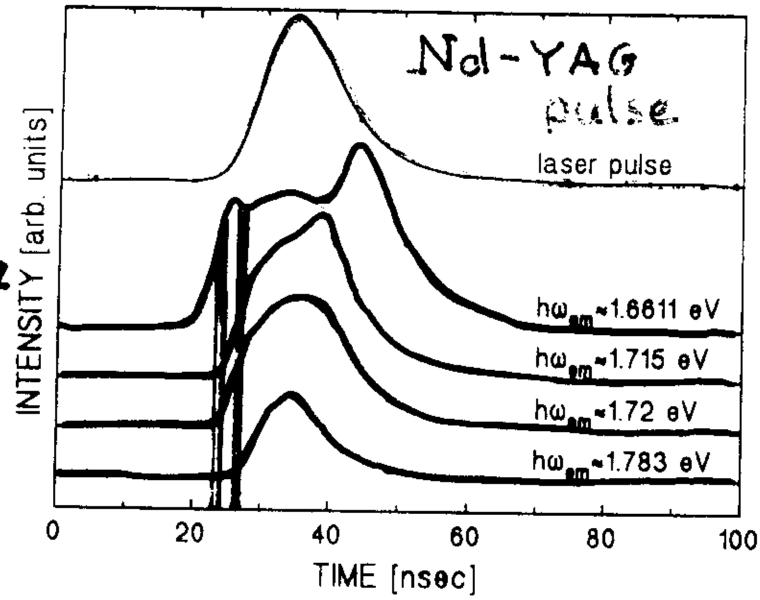
Remarkable broadening
Low energy tail ?



Time-resolved (~1 nsec) experiments on single GaAs/GaAlAs structures

$P^{pulse}_{max} \simeq$
$\simeq 1\ MW/cm^2$

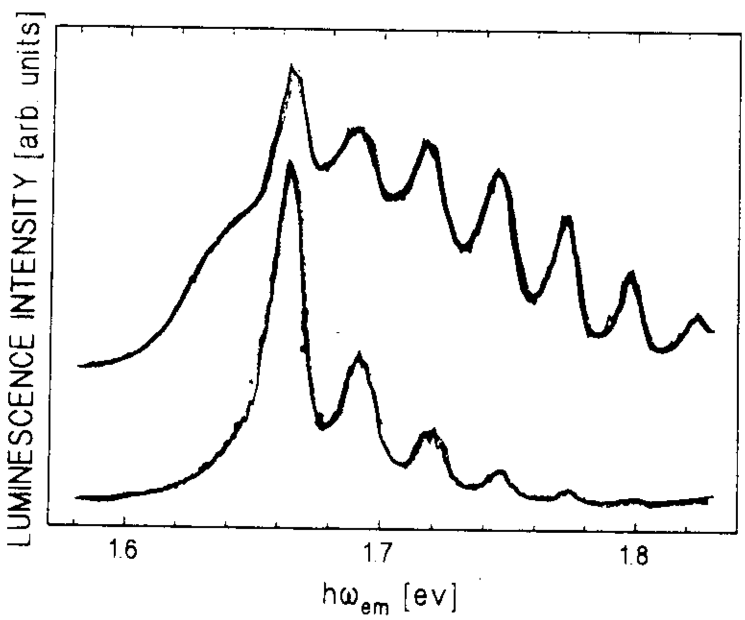
Luminescence signals



$d = 40\ \mathring{A}$

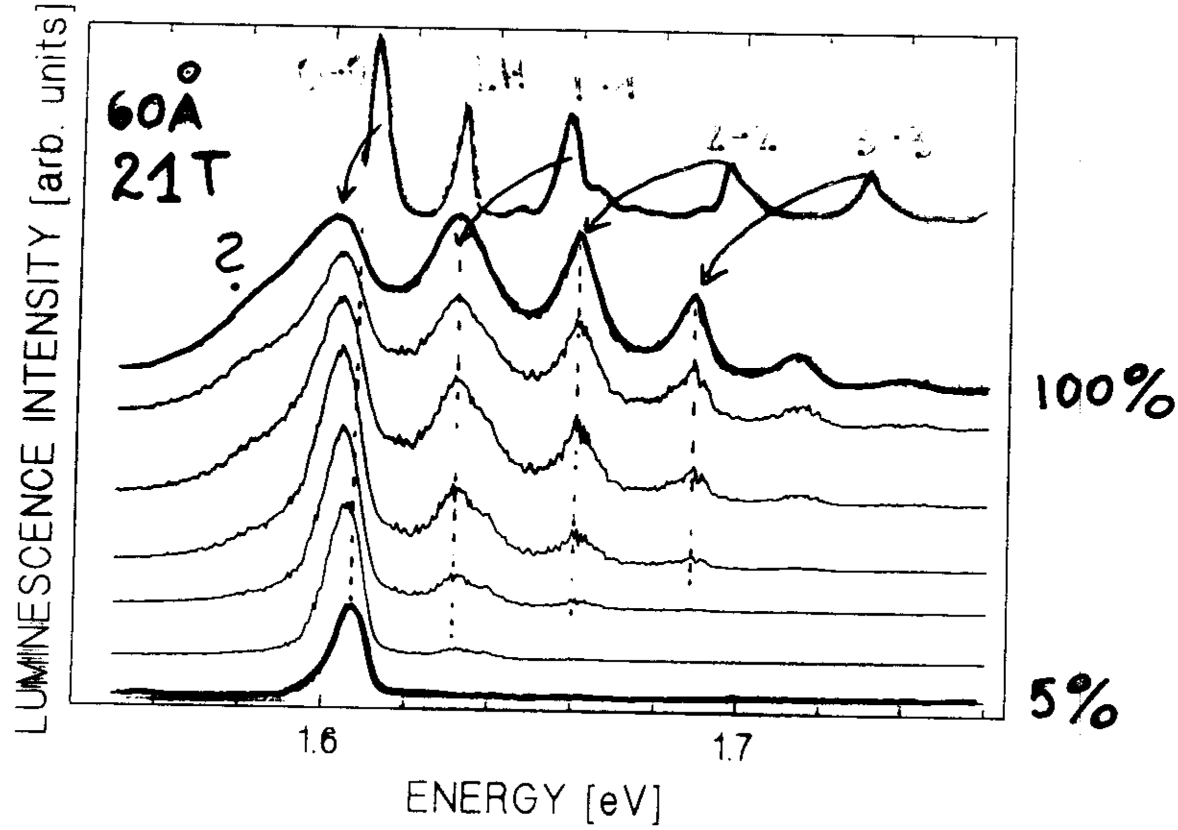
$B = 28T$

$\Delta t = 1.5 ns$



Better resolution
lower "carrier temperature"

$P_d^{MAX} \simeq$ 0.2 MW/cm²

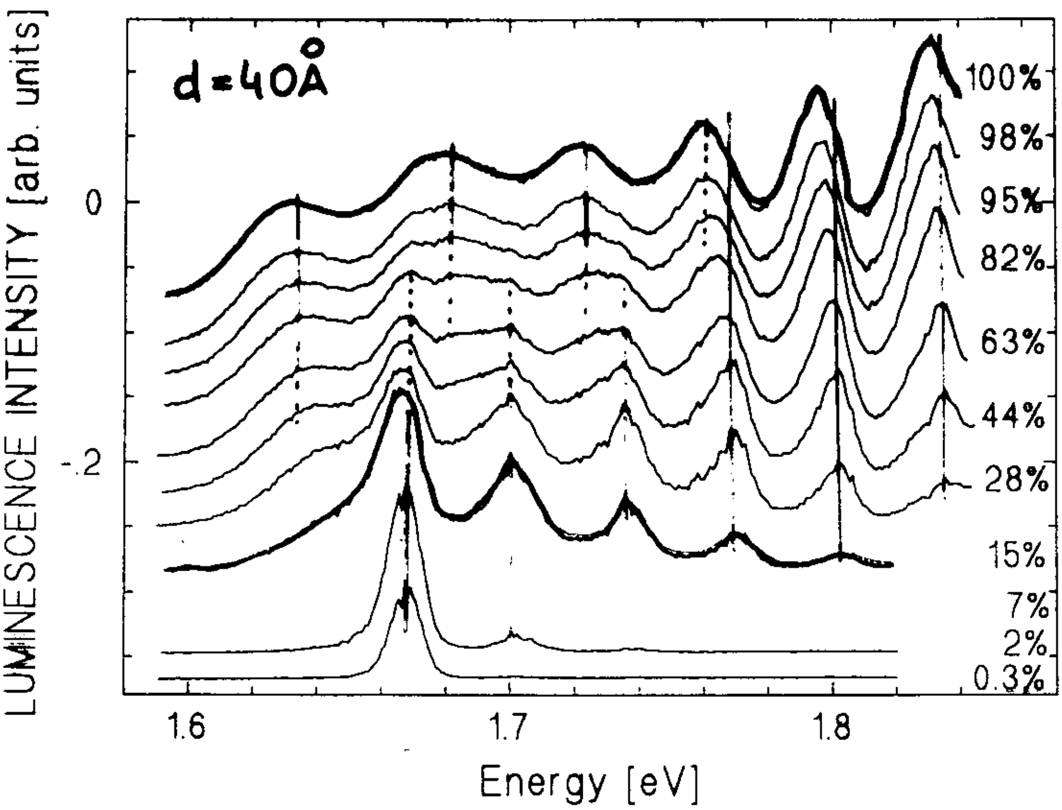


— absorption
— emission

but main observations
in agreement with previous results

Resuts at higher fields and higher excitation levels

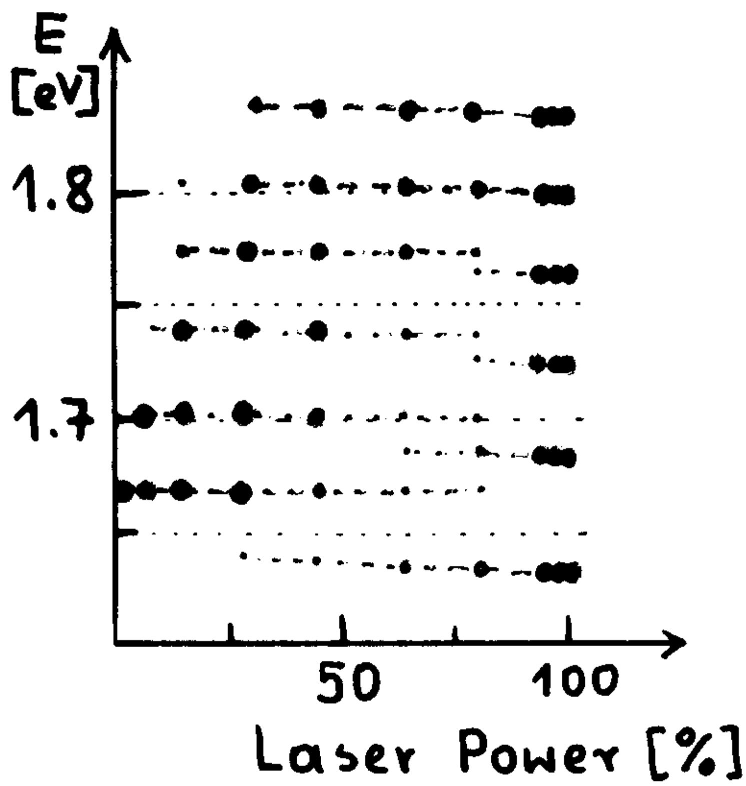
$B = 28T \quad P_d^{Max} \simeq 1\,MW/cm^2$



New Landau level structure at high excitation intensities in high magnetic fields ?!

Two-phase-like behavior ?

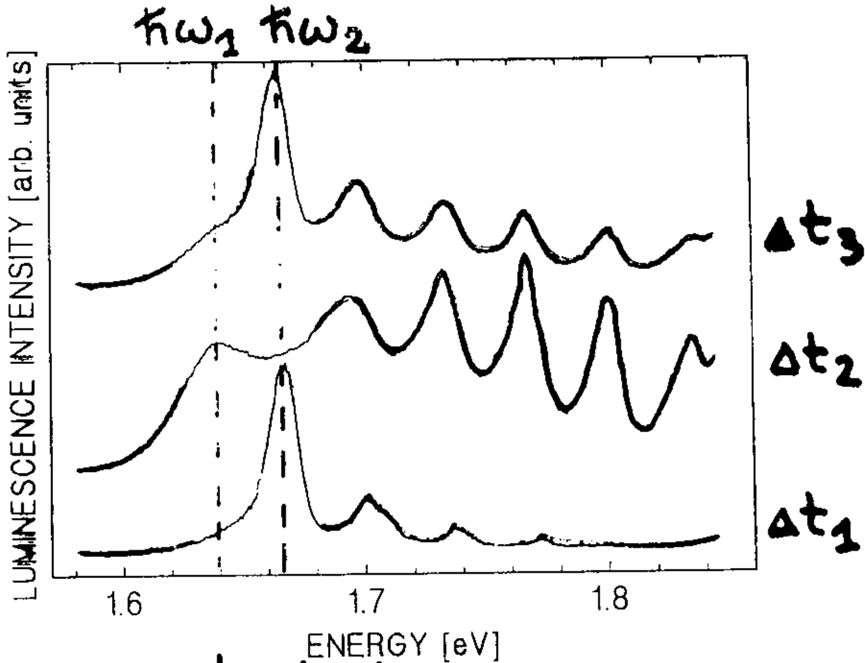
Energy positions of
emission peaks vs.
excitation power .



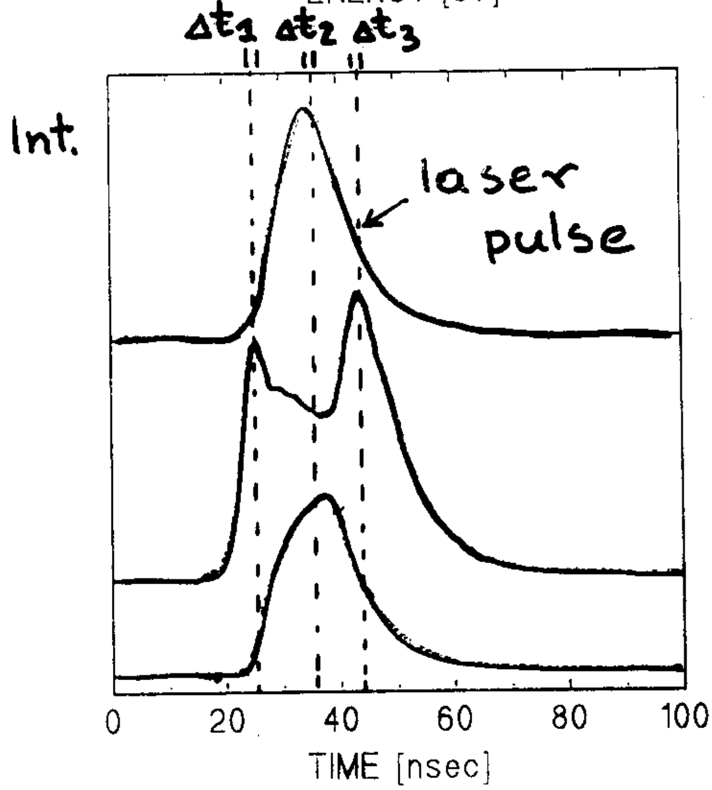
— low density
.... high density

Two-phase-like behavior ?

GaAs/GaAlAs
d = 40Å
B = 28T
$P_d^{max} \simeq 0.6\ MW/cm^2$



Time resolved signals at ħω1 and ħω2



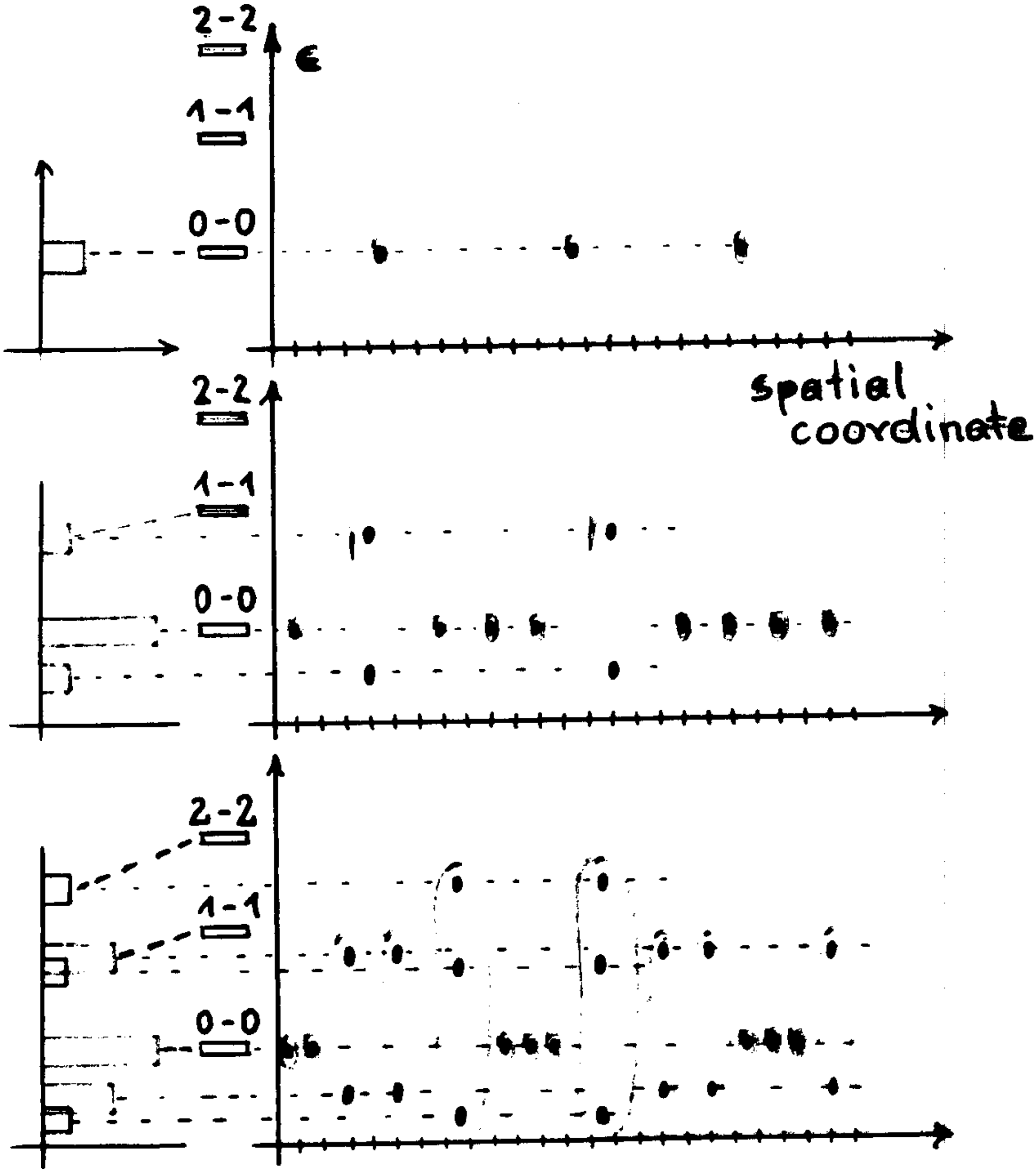
,2'

Interpretation ???

! The system behaves very locally in the real space

! Emission arises from small regions with different filling factors

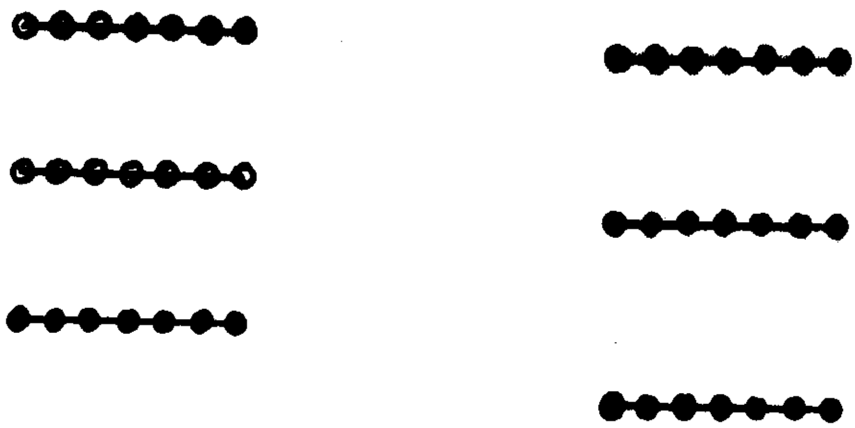
"excitonic molecules" ?



B2

Interpretation ???

Would it be possible?



$$\langle \epsilon \rangle_1 > \langle \epsilon \rangle_2$$

??
- asymmetry in the effective mass
- nonparabolicity
- heavy-light hole mixing