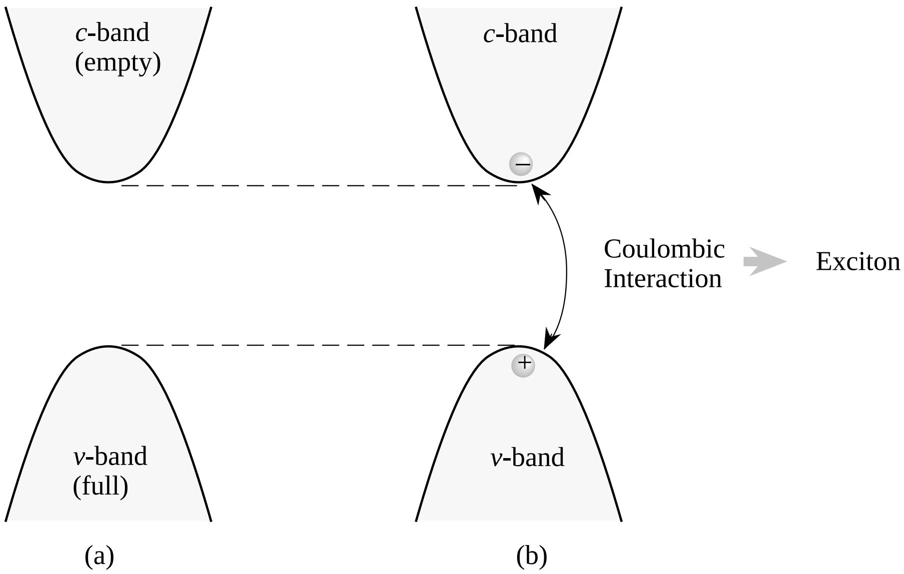
Chapter 10

EXCITONIC EFFECTS AND MODULATION OF OPTICAL PROPERTIES

EXCITONS: ELECTRON-HOLE PAIRS

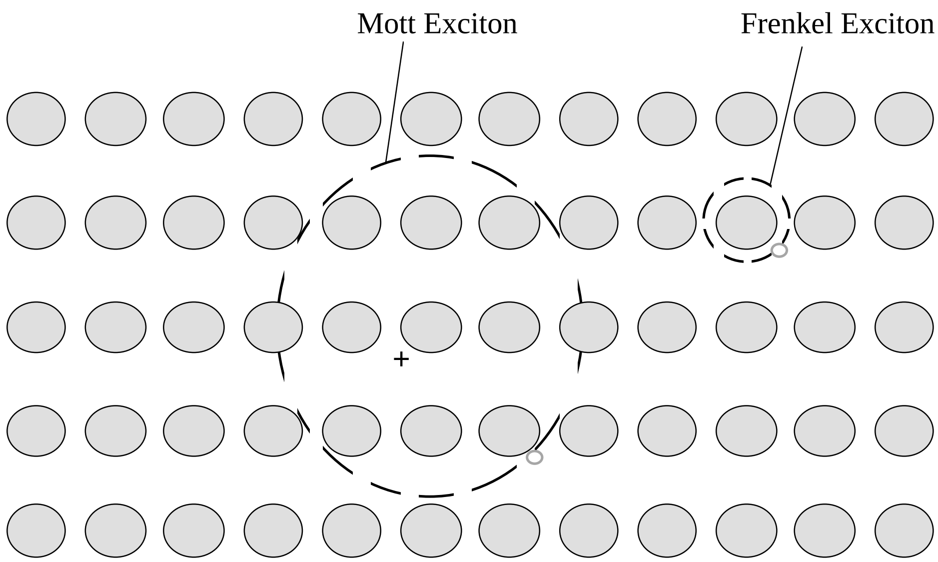


(a) The bandstructure in the independent electron picture and (b) the Coulombic interaction between the electron and hole which would modify the band picture.

Exciton energies (referred to the bandgap):

$$E_{n\mathrm{k}_{\mathrm{ex}}} = E_n + \frac{\hbar^2}{2\left(m_e^* + m_h^*\right)} K_{\mathrm{ek}}^2$$

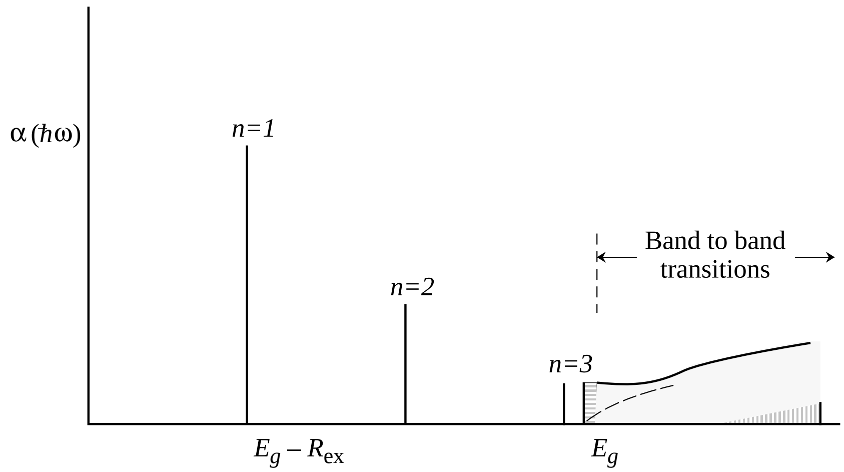
$$E_n = -\frac{m_r^* e^4}{2(4\pi\varepsilon)^2\hbar^2}\frac{1}{n^2}$$



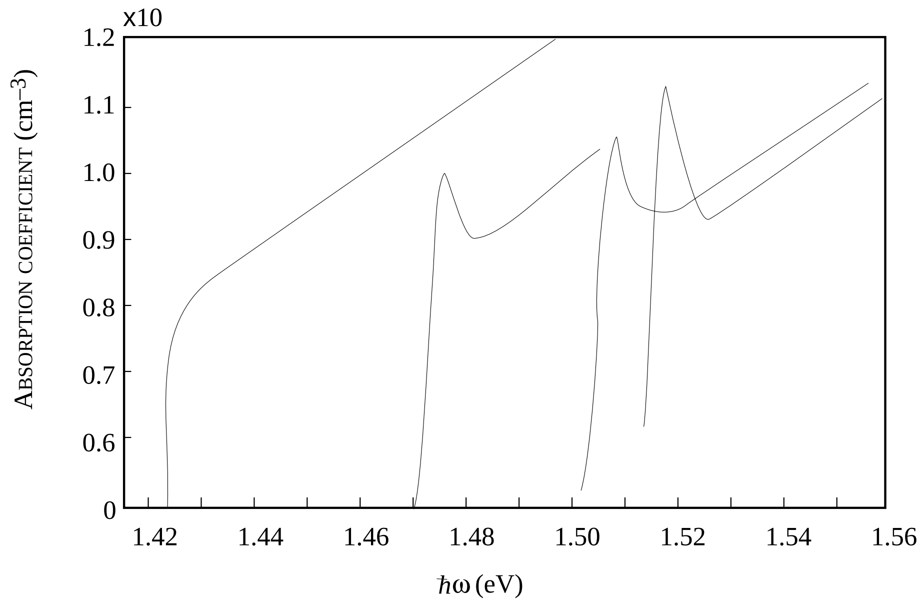
A conceptual picture of the peiodic envelope function extent of the Frenkel and Mott excitons. The Frenkel exciton periodic function is of the extent of a few unit cells while the Mott exciton function extends over many units cells.

OPTICAL PROPERTIES: INCLUSION OF EXCITON EFFECTS

At low temperatures in high quality materials one can see excitonic structure along with band-to-band transitions.



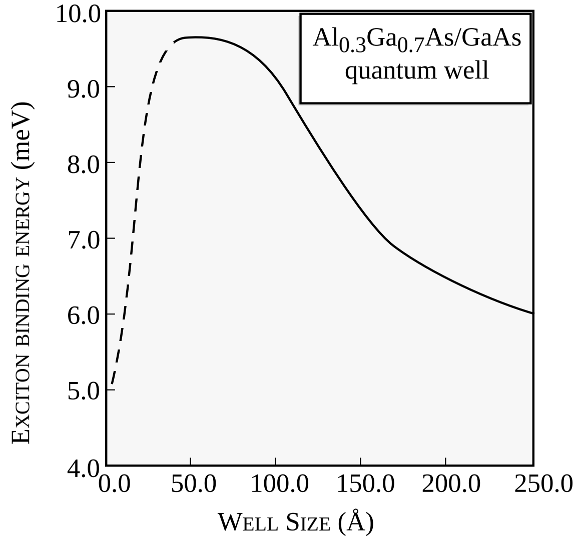
A schematic picture of the absorption spectra with (solid line) and without (dashed line) excitonic effects.



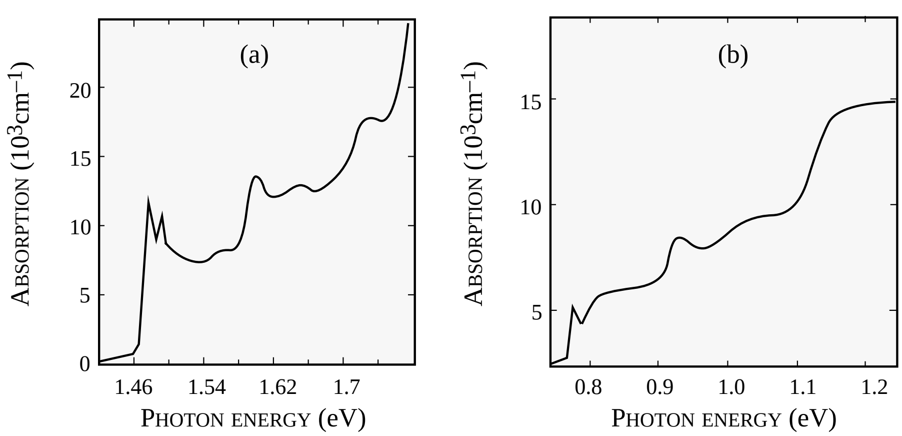
Typical optical transitions in GaAs. As can be seen, the excitonic peak essentially merges with the band-to-band absorption onset at room temperature. (see M.D. Sturge, *Physical Review*, **127**, 768 (1962).)

EXCITONS IN QUANTUM WELLS

Exciton binding energy increases in quasi-2D systems



Variations of the heavy-hole exciton binding energy as a function of well size in $GaAs/Al_{0.3}Ga_{0.7}As$ wells. The binding energy of the infinite barrier well should approach four times the 3D exciton binding energy as the well size goes to zero.

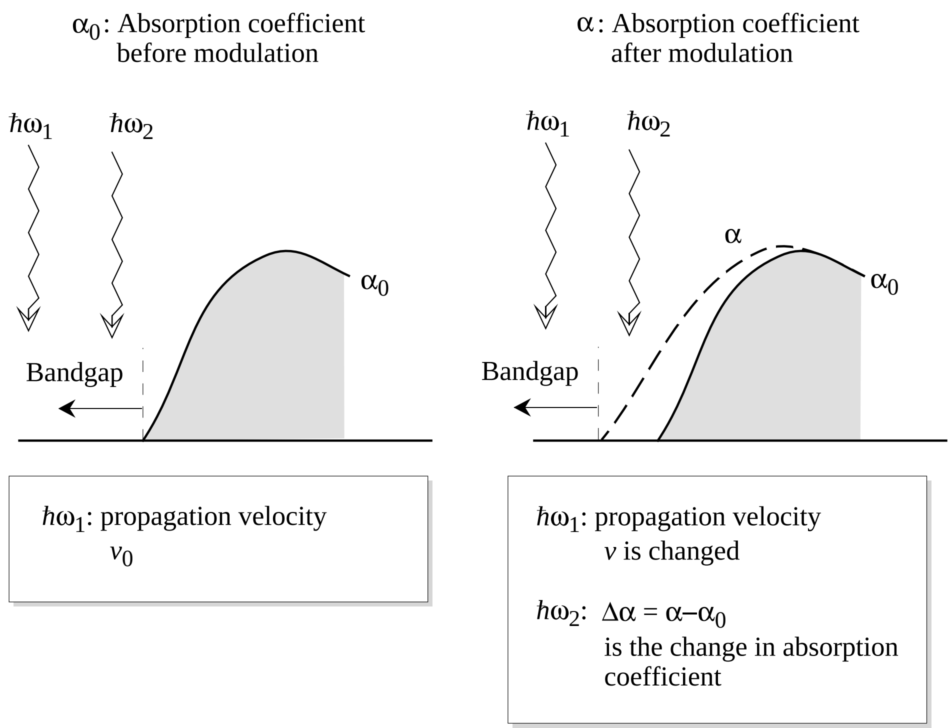


A comparison of absorption sepctra in (a) 100 Å $GaAs/Al_{0.3}Ga_{0.7}As$ and (b) $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As$ quantum wells. The excitons in InGaAs suffer alloy broadening which reduces their sharpness. (After D.S. Chemla, *Nonlinear Optics: Materials and Devices,* eds. C. Flytzanis and J.L. Oudar, Springer-Verlag, New York (1986).)

ELECTRO-OPTIC EFFECT

An electric field can alter the electronic spectra of a material and thus modify the refractive index or dielectric constant.

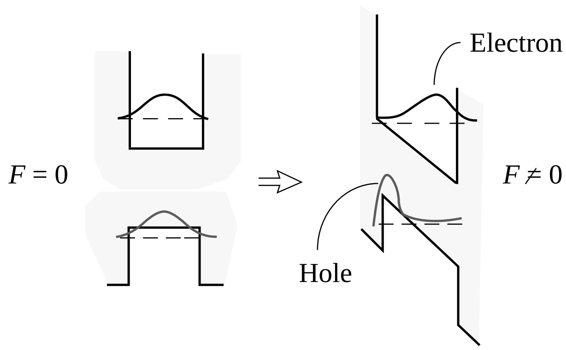
➡ The effect can be exploited for optical switches.



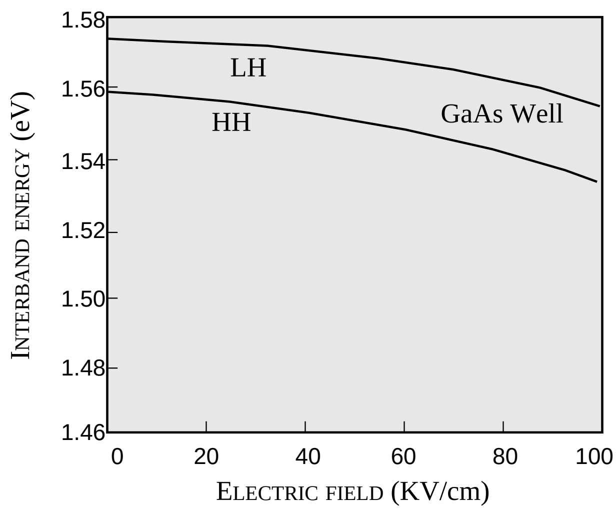
A schematic of the effect of a change in optical properties of a material on an optical beam. For energy $\hbar\omega^1$, the main effect of the change in the optical properties is a change in propagation velocity. For $\hbar\omega^2$, the effect is a change in intensity.

QUANTUM CONFINED STARK EFFECT

A transverse electric field alters the shape of quantum wells and modifies the effective bandgap.



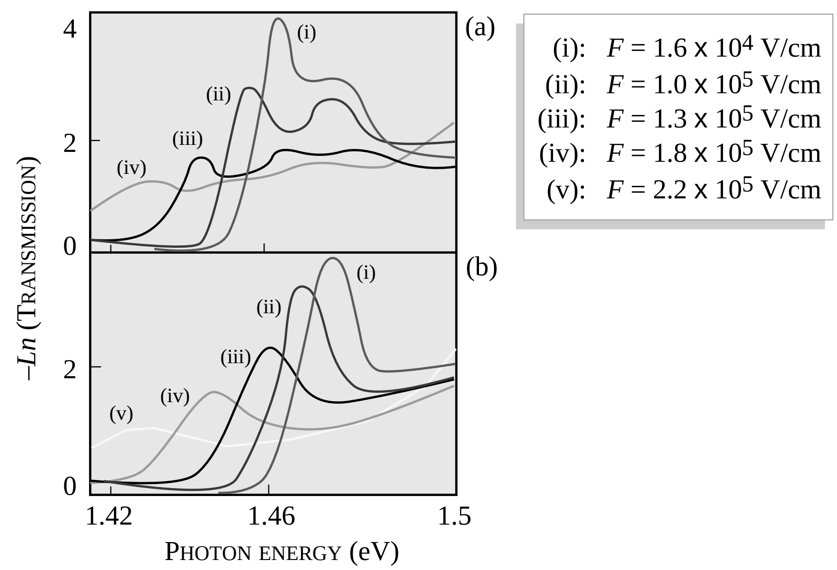
A schematic showing how an electric field alters the quantum well shape and the electron and hole wavefunctions.



Calculated variation of the ground state HH and LH (to conduction band ground state) intersubband transition energies as a function of electric field. The well is a 100 Å GaAs/$Al_{0.3}Ga_{0.7}As$.

QUANTUM CONFINED STARK EFFECT: POLARIZATION EFFECTS

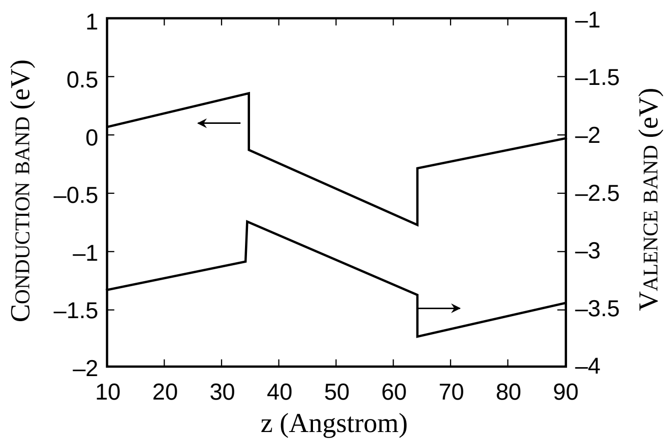
Due to the different polarization selection rules for HH to electron and LH to electron transitions QCSE has strong polarization dependence.



Measured polarization dependent transmittances in GaAs/AlGaAs (100 Å) multiquantum well structures when light is coming in the waveguide geometry. (a) Incident polarization parallel to the plane of the layers. (b) Incident polarization perpendicular to the plane of layers. (After D.A.B. Miller, et al., *IEEE J. Quantum Electronics,* QE-22, 1816 (1986).)

POLAR HETEROSTRUCTURES: InGaN/GaN QUANTUM WELLS

For *c*-axis growth InGaN/GaN has strong interface polar charge
→ quantum wells are under a large electric field.



Band profile for 30 Å $In_{0.18}G_{0.82}aN$/GaN quantum well grown lattice-matched to GaN in the (0001) orientation.

Electron-hole recombination times are long due to the small *e*-*h* overlap.