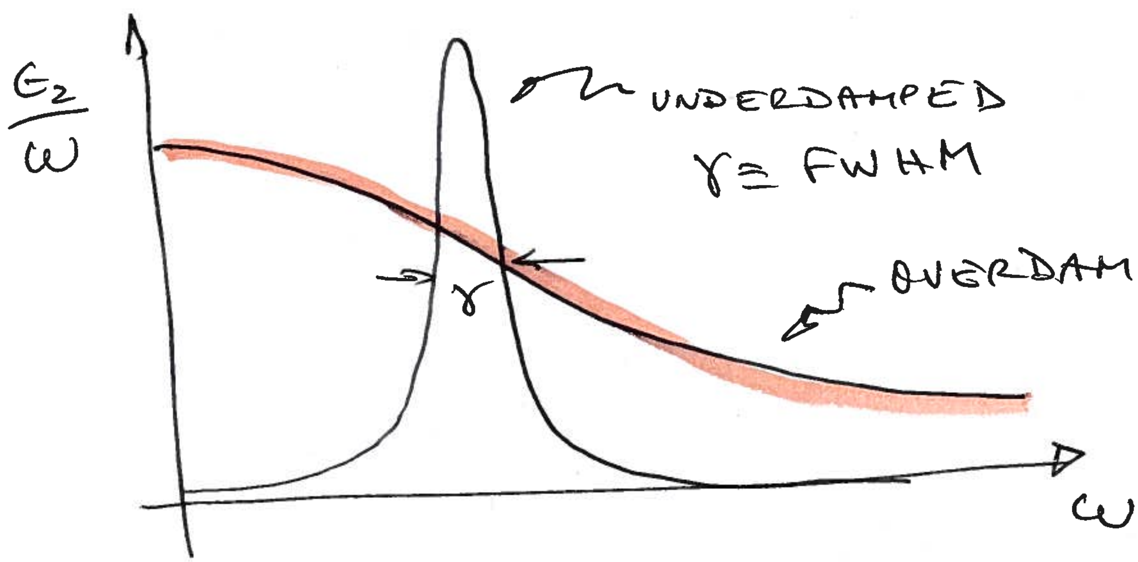
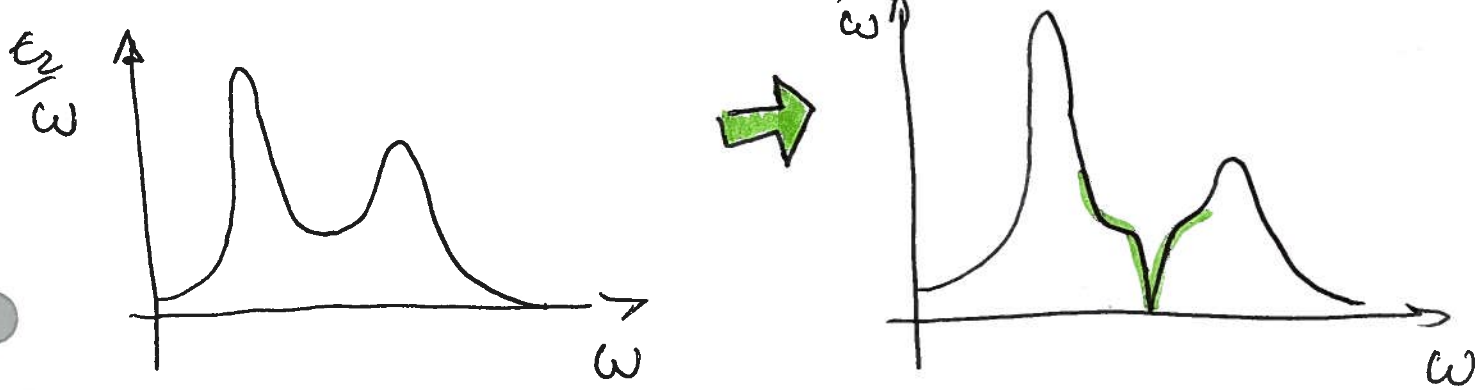
BACK TO LORENTZ' MODEL

$$\epsilon = \epsilon_\infty + \frac{4\pi N e^2 / m}{\omega_0^2 - \omega^2 - i\omega\gamma}$$

$$\epsilon_2 = \frac{4\pi N e^2}{m} \frac{\omega \gamma}{(\omega_0^2 - \omega^2)^2 + \omega^2 \gamma^2}$$

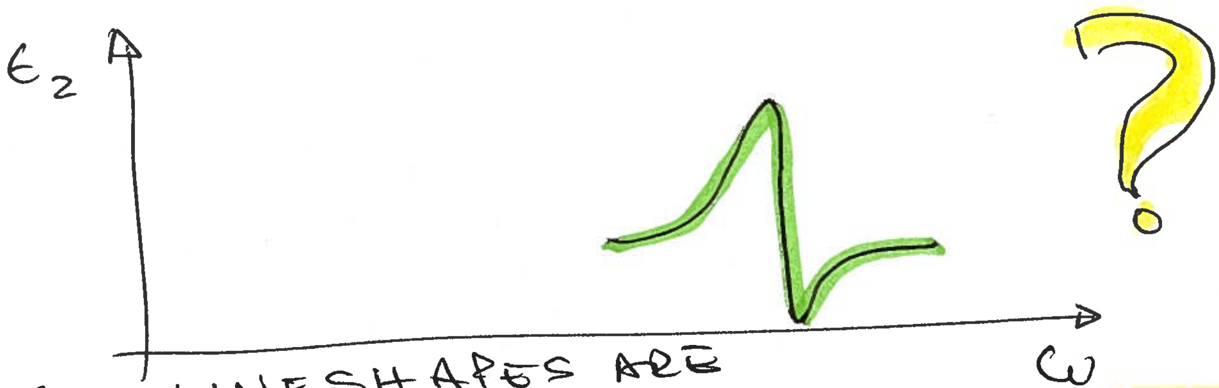


TWO OSCILLATORS



SAME SYMMETRY

IN THE CASE WHERE ONE OF THE OSCILLATORS IS OVERDAMPED AND THE SECOND ONE IS WEAKLY DAMPED (2)



SUCH LINESHAPES ARE USUALLY ATTRIBUTED TO FANO INTERFER(E
COUPLING OF A DISCREET STATE W/ CONTINUUM (OVERDAMPED OSCILLATOR)

SUCH A PROBLEM WAS CONSIDERED BY B. SZIGETI [Proc. Roy. Soc. A 258, 377 (60)]
QUANTUM MODEL INVOLVING ONE & TWO-PHONON CONTRIBUTIONS

NOTE: FOR ϵ (linear permittivity), HARMONIC OSCILLATORS & TWO-LEVEL SYSTEMS CAN'T BE DISTINGUISHED

HERE, WE'LL DISCUSS A CLASSICAL PHENOMENOLOGICAL MODEL THAT EXHIBITS INTERFERENCE EFFECTS

{ BARKER & HOPFIELD (64)
ALZAR et. al (2002)

SIMILAR TO ELECTROM. INDUCED TRANSPARENCY (EIT)

Fano Interferences

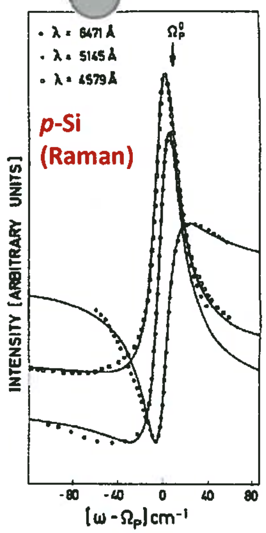


FIG. 2. Portion of the spectrum corresponding to scattering by zone-center phonons for different scattering wavelengths. The solid lines are theoretical fits with Eq. (12) to the experimental curves (discrete points). Ω_p^i and Ω_p denote the zone-center phonon frequency of the intrinsic and doped materials, respectively.

Phys. Rev. B 9, 4344

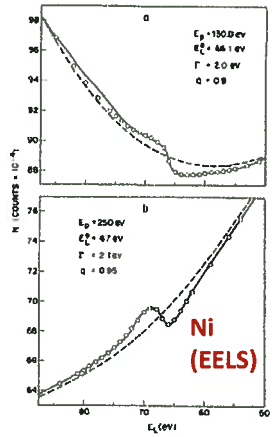
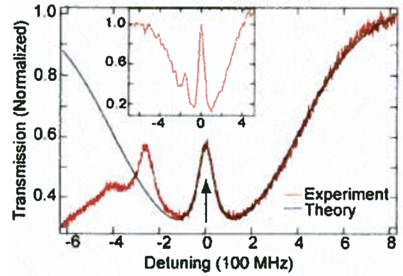


FIG. 1. Plots of the electron energy-loss distribution for Ni(001) in the vicinity of the 3p excitation for two different values of the primary energy E_p. The full lines are experimental $N(E_L)$ curves. The circles indicate values calculated from Eq. (1). The background curves $N_0(E)$ (broken lines) and the values assigned to M^2 in Eq. (1) were (a) $N_0(E) = 265.21 - 40.393E^{1/2} + 2.7566E$, $M^2 = 0.9$; (b) $N_0(E) = 934.50 - 142.42E^{1/2} + 5.691E$, $M^2 = 1.3$. The background parameters were generated by assuming that the contribution of the resonance to the background was negligible at points 25 eV on either side of E_L^1. The value of the background at E_L^0 was then taken as a parameter and adjusted along with Γ and q so as to give a best fit. Using this procedure a unique fit could be obtained for the parameters to within the uncertainties quoted in the text.

Phys. Rev. Lett. **33**, 1372

Rb vapor (EIT)



Phys. Rev. Lett. **97**, 023603

WG Modes

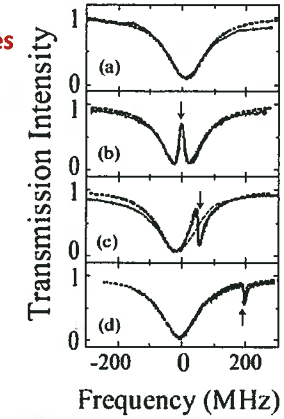


Fig. 2. Solid curves and dashed curves are experimental and theoretical spectra in the coupled microsphere resonators under the following conditions: (b) $\nu_1 = \nu_2$, (c) $\nu_1 < \nu_2$, $\Delta\nu_{12} = \nu_2 - \nu_1 < \delta\nu_1$, and (d) $\nu_1 < \nu_2$, $\Delta\nu_{12} > \delta\nu_1$. Arrows indicate the resonance frequency of the second sphere, ν_2. The detuning parameter is (b) $\Delta\nu_{12} = 0$ MHz, (c) $\Delta\nu_{12} = 49$ MHz, and (d) $\Delta\nu_{12} = 204$ MHz. Other parameters used in the calculations are $x_1 = 0.999{,}432$, $x_2 = 0.999{,}973$, and $y_1 = 0.999{,}651$ in all figures. The coupling parameter between two spheres is $y_2 = 1$ in 2(a), while $y_2 = 0.999{,}999{,}960$ in 2(b)–2(d). The gray dashed line in 2(c) is the transmission dip by the naked first sphere as a reference. (a) is the spectrum observed without S_2.

JOSA B **26**, 813

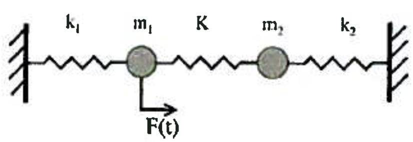


Fig. 2. The mechanical model used to simulate EIT.

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Phys. Rev. **135**, A1732 (1964)

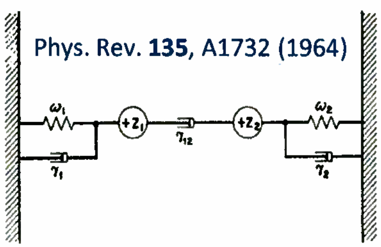
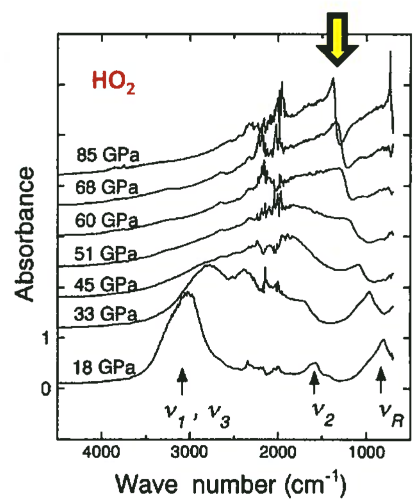
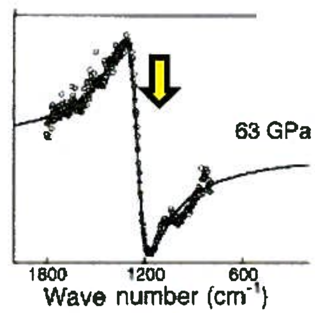


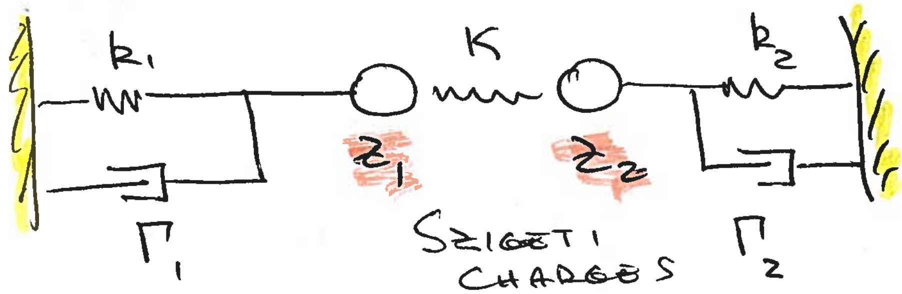
FIG. 2. Mechanical model of two optic mode oscillators with interaction damping. The dashpots γ_1, γ_2, and γ_{12} provide damping forces proportional to velocity.



Phys. Rev. Lett. **76**, 784



Coupled Modes: Interference-Induced Transparency



COUPLING GIVES XTRA TERM IN THE POTENTIAL ENERGY

$$U_c = \frac{1}{2} K (u_1 - u_2)^2$$

$$\begin{cases} \ddot{u}_1 + (k_1 + K) u_1 - K u_2 + \Gamma_1 \dot{u}_1 = Z_1 e E \\ \ddot{u}_2 + (k_2 + K) u_2 - K u_1 + \Gamma_2 \dot{u}_2 = Z_2 e E \end{cases}$$

XTERN FIE

$$\Rightarrow P = e Z_1 u_1 + e Z_2 u_2$$

FOR $E = E_0 e^{-i\omega t}$

$$\left[\begin{array}{cc|c} -\omega^2 + (k_1 + K) - i\omega\Gamma_1 & -K & Z_1 e E_0 \\ -K & -\omega^2 + (k_2 + K) - i\omega\Gamma_2 & Z_2 e E_0 \end{array}\right]$$

$$u_1 = \frac{K Z_2 + \Sigma_2 Z_1}{\Sigma_1 \Sigma_2 - K^2} e E_0$$

$$u_2 = \frac{K Z_1 + \Sigma_1 Z_2}{\Sigma_1 \Sigma_2 - K^2} e E_0$$

$$P = \frac{\Sigma_1 z_2^2 + \Sigma_2 z_1^2 + 2K z_1 z_2}{\Sigma_1 \Sigma_2 - K^2} e^2 E_0$$

$$\Sigma_{1,2} = -\omega^2 + (K_{1,2} + K) - i\omega\Gamma_{1,2}$$

IF THERE IS NO COUPLING,

$$P = \frac{z_1^2}{\Sigma_1} + \frac{z_2^2}{\Sigma_2}$$

TAKE $\begin{cases} \Sigma_1 \approx -i\omega\Gamma \\ \Sigma_2 = (\omega_0^2 - \omega^2) \end{cases}$ (OVERDAMPED)

$$\text{Im}\,\epsilon = \omega\Gamma \frac{\left[(\omega_0^2 - \omega^2) z_1 + z_2 K\right]^2}{\omega^2\Gamma^2(\omega_0^2 - \omega^2)^2 + K^4}$$

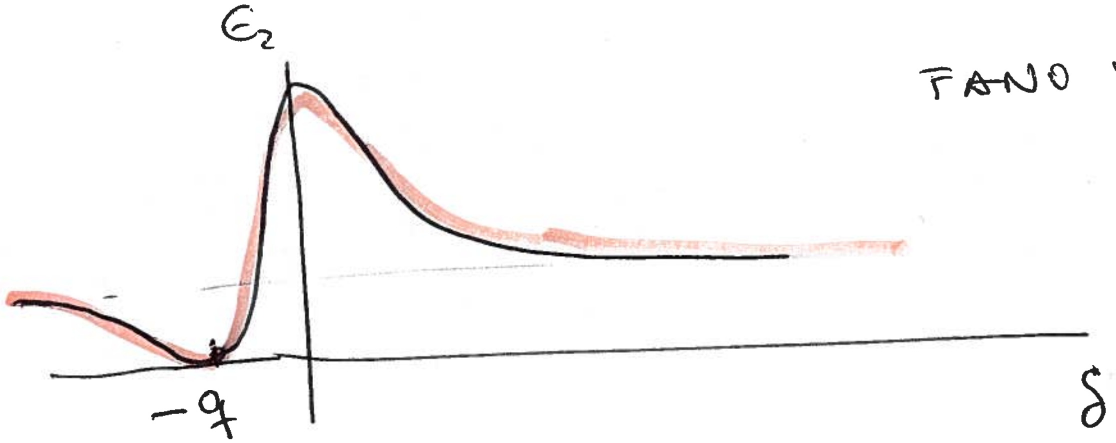
FOR $(\omega_0^2 - \omega^2) = -\frac{z_2}{z_1} K$, $\epsilon_2 \equiv 0$

COUPLING-INDUCED TRANSPARENCY

FANO - FORM:

$$\omega_0^2 - \omega^2 \approx (\omega_0 - \omega)\, 2\omega_0$$

$$\epsilon_2 \propto \omega_0 \Gamma \frac{\left[(\omega_0 - \omega) 2\omega_0 z_1 + z_2 \kappa\right]^2}{4\omega_0^4 \Gamma^2 (\omega_0 - \omega)^2 + \kappa^4} \propto \frac{(q + \delta)^2}{1 + \delta^2}$$



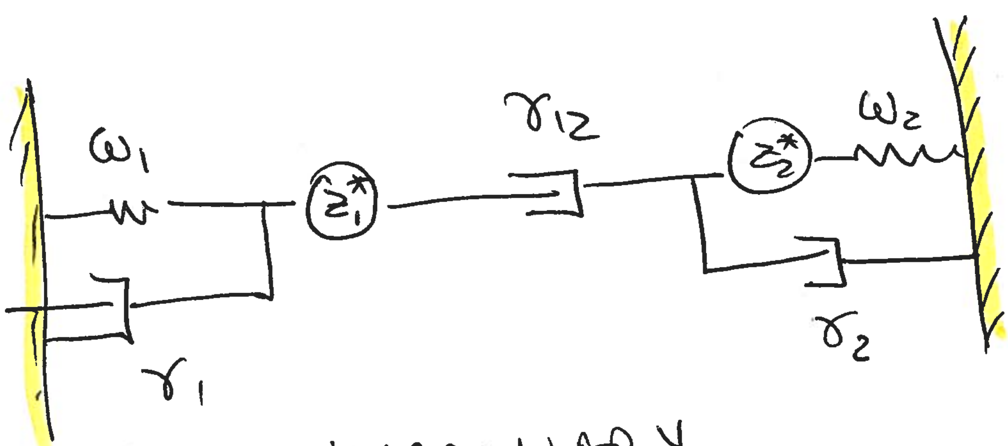
FANO LINESHAPE

PHYSICAL INTERPRETATION:

USE UNITARY TRANSFORMATION

$$\begin{pmatrix} w_1 \\ w_2 \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} u_1 \\ u_2 \end{pmatrix}$$

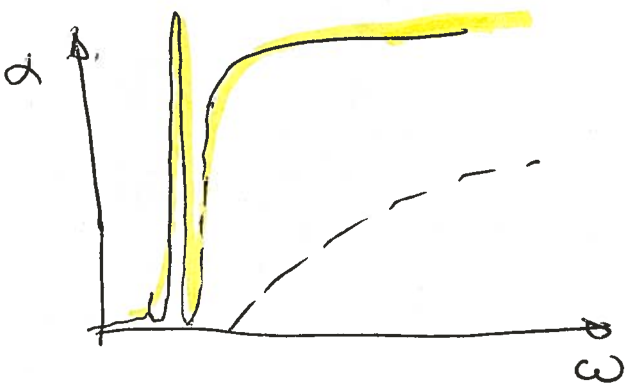
ϵ_2 HAS A MINIMUM WHEN $W_1 = W_2 = 0$



IMAGINARY COUPLING

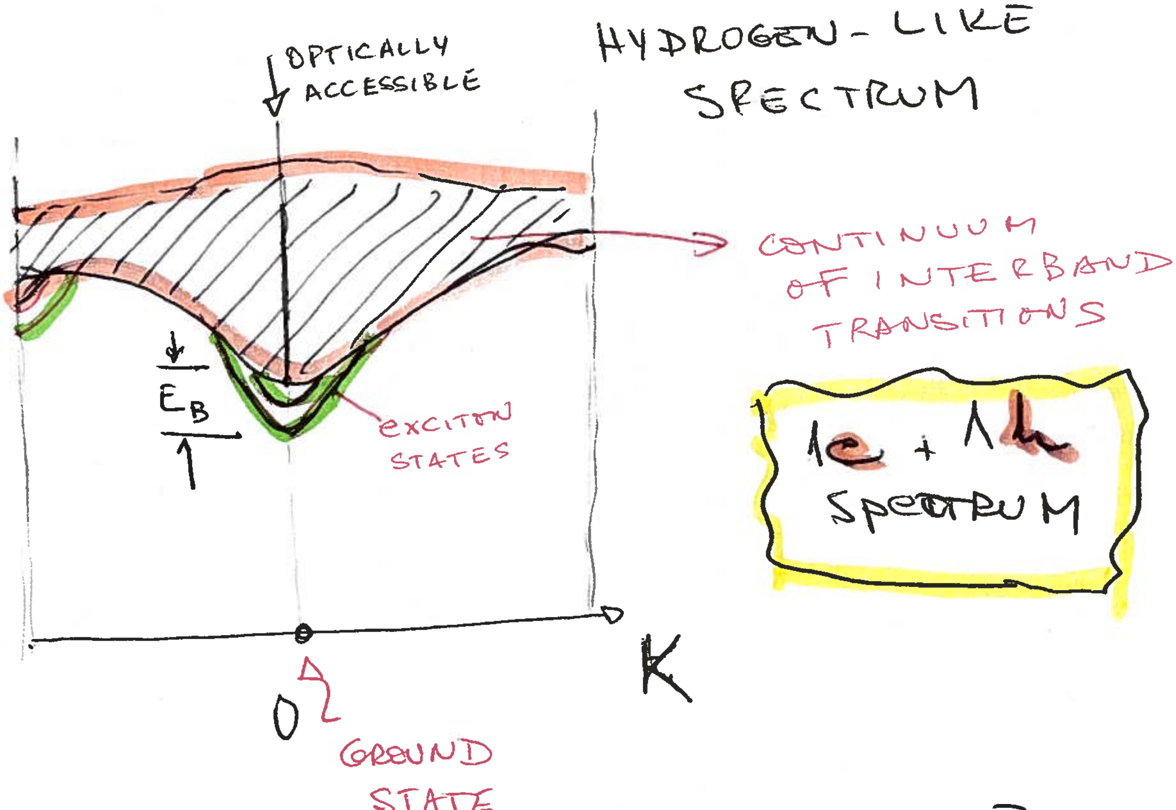
EXCITONS

- Absorption is significantly larger than what is predicted for interband transitions
- Occurrence of sharp absorption lines below the gap.



Coulomb interaction between e^- and h^+

Hydrogen-like spectrum



$$\boxed{\text{1e + 1h spectrum}}$$

$$E_B \sim \frac{e^2}{a_0}$$

IF $a_0 \sim a_L$ ⇒ FRENKEL EXCITON

IF $a_0 \gg a_L$ ⇒ WANNIER EXCITON

FRENKEL EXCITONS OCCUR IN ORGANIC COMPOUNDS, MOLECULAR CRYSTALS & RARE GAS SOLIDS - WEAKLY-COUPLED COLLECTION OF ATOM OR MOLECULAR-LIKE SYSTEMS - VERY WEAK DISPERSION

WANNIER EXCITONS CAN BE DESCRIBED USING EFFECTIVE-MASS THEORY

$$H = -\frac{\hbar^2}{2m_e}\nabla_e^2 - \frac{\hbar^2}{2m_h}\nabla_h^2 - \frac{e^2}{\varepsilon r}$$

SOLUTIONS ARE

$$E = \frac{\hbar^2 K^2}{2(m_e + m_h)} - \frac{1}{n^2}\frac{\mu e^4}{2\hbar^2 \epsilon^2}$$

↳ dielectric constant

$$\boxed{a_0 = 0.52\,\frac{\epsilon}{\mu}}$$

$$\mu = \frac{m_e m_h}{m_e + m_h} \qquad E_B = 13.6\,\frac{\mu/m_0}{\epsilon^2}\ \mathrm{eV}$$

FOR GaAs, $\epsilon \approx 10$ & $\frac{\mu}{m_0} \approx 0.07$ ⇒ $E_B \approx 10\,\mathrm{meV}$