ECE 656: Electronic Transport in Semiconductors Fall 2017

Intervalley Phonon Scattering

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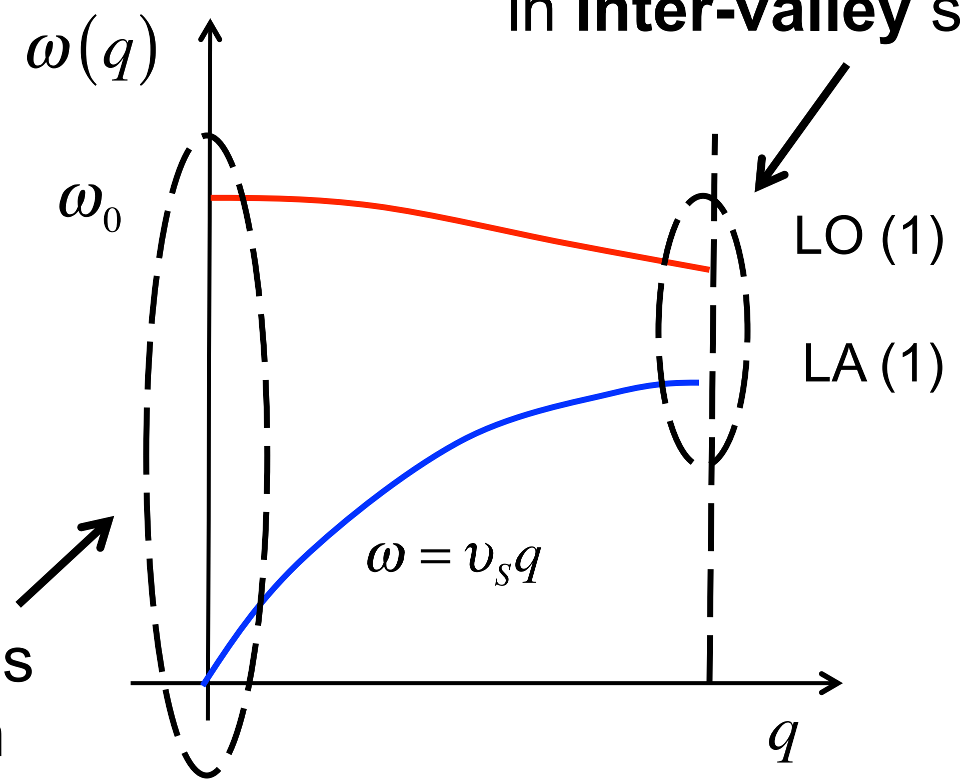
Outline

1) Quick re-cap
2) Equivalent valleys (Si)
3) Inequivalent valleys (GaAs)
4) Summary

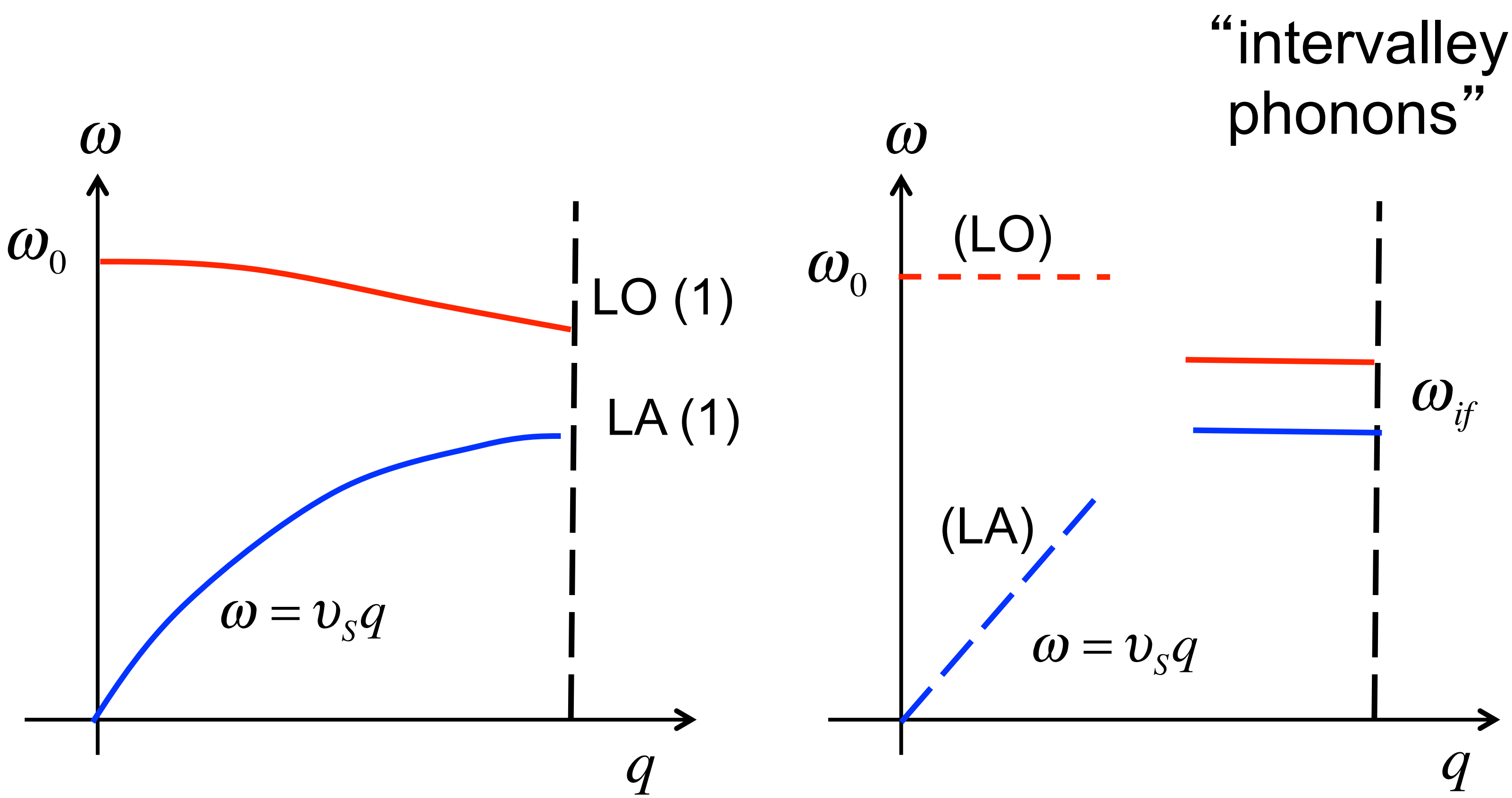
Phonon dispersion

These phonons are involved in **inter-valley** scattering



These phonons are involved in **intra-valley** scattering

Simplified phonon dispersions



Transition rate for IV phonon scattering

$$S(\vec{p},\vec{p}') = \frac{\pi}{\Omega\rho\,\omega}\left|K_q\right|^2\left(N_\omega + \frac{1}{2} \mp \frac{1}{2}\right)\delta\left(\vec{p}' - \vec{p} \mp \hbar\vec{q}\right)\delta\left(E' - E \mp \hbar\omega\right)$$

$$\left|K_q\right|^2 = q^2 D_A^2 \quad \text{acoustic}$$

$$\left|K_q\right|^2 = D_0^2 \quad \text{optical}$$

$$\left|K_q^{if}\right|^2 = q_{if}^2 D_A^2 \rightarrow D_{if}^2$$

Intervalley phonon scattering will be treated like optical phonon scattering.

The phonons of interest are near the zone boundary where ω is approximately constant for both acoustic and optical phonons. The wavevector that connects the initial and final valleys is large and nearly constant.

Transition rate for IV phonon scattering

$$S(\vec{p},\vec{p}\,') = \frac{\pi}{\Omega\rho\,\omega}\left|D_{if}\right|^2\left(N_\omega + \frac{1}{2} \mp \frac{1}{2}\right)\delta\left(E' - E \mp \hbar\omega_{if}\right)$$

$$S(\vec{p},\vec{p}\,') = \frac{2\pi}{\hbar}U_{if}\left(N_\omega + \frac{1}{2} \mp \frac{1}{2}\right)\frac{1}{\Omega}\delta\left(E' - E \mp \hbar\omega_{if}\right) \qquad U_{if} = \frac{\pi}{2\Omega\rho\,\omega}\hbar\left|D_{if}\right|^2 Z_f$$

$$\frac{1}{\tau(E)} = \frac{1}{\tau_m(E)} \propto Z_f D'\left(E \pm \hbar\omega_{if}\right)$$

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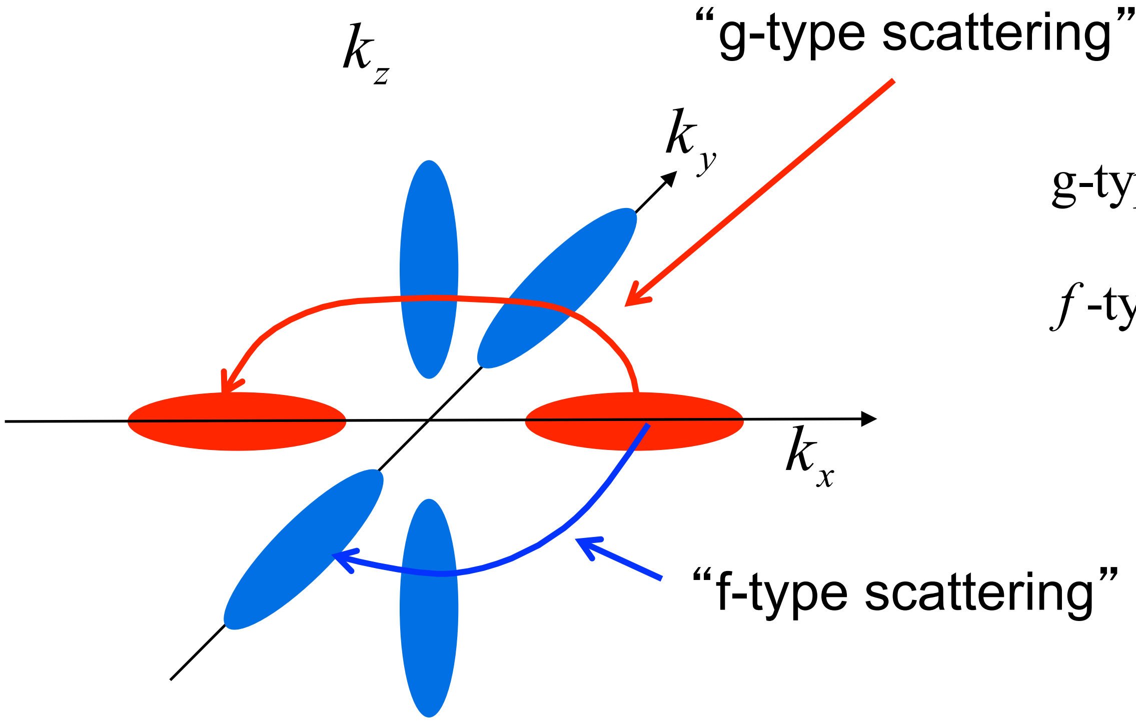
Equivalent intervalley scattering in Si

Si conduction band



g-type: $Z_f = 1 \quad \Delta E_{fi} = 0 \text{ eV}$

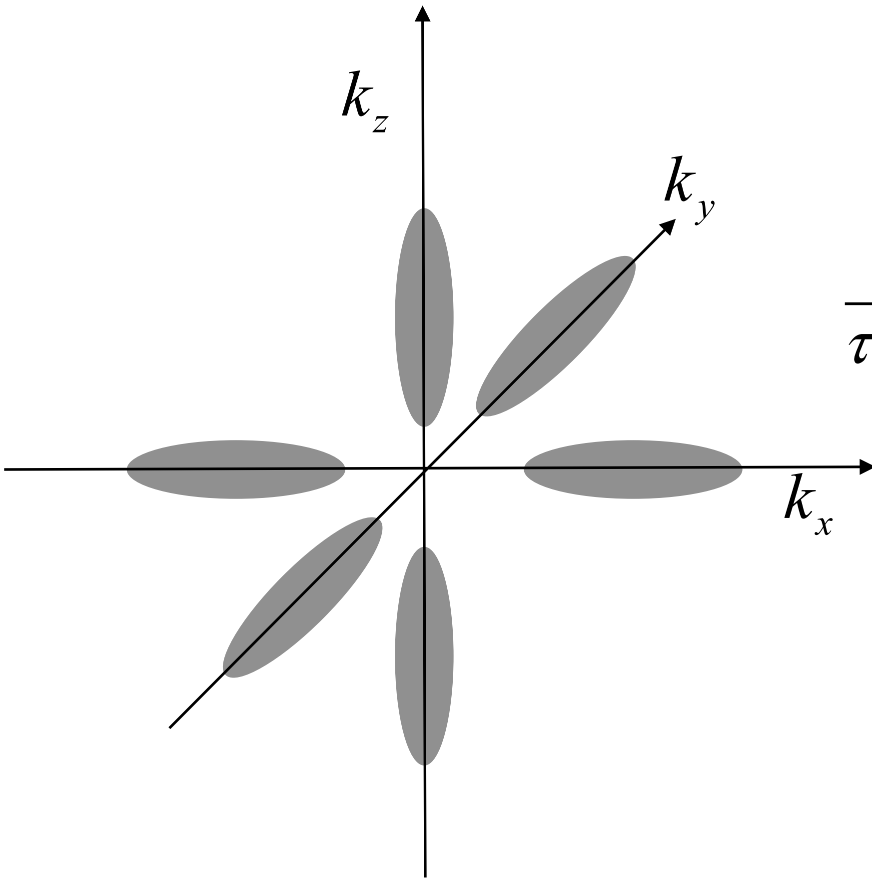
f-type: $Z_f = 4 \quad \Delta E_{fi} = 0 \text{ eV}$

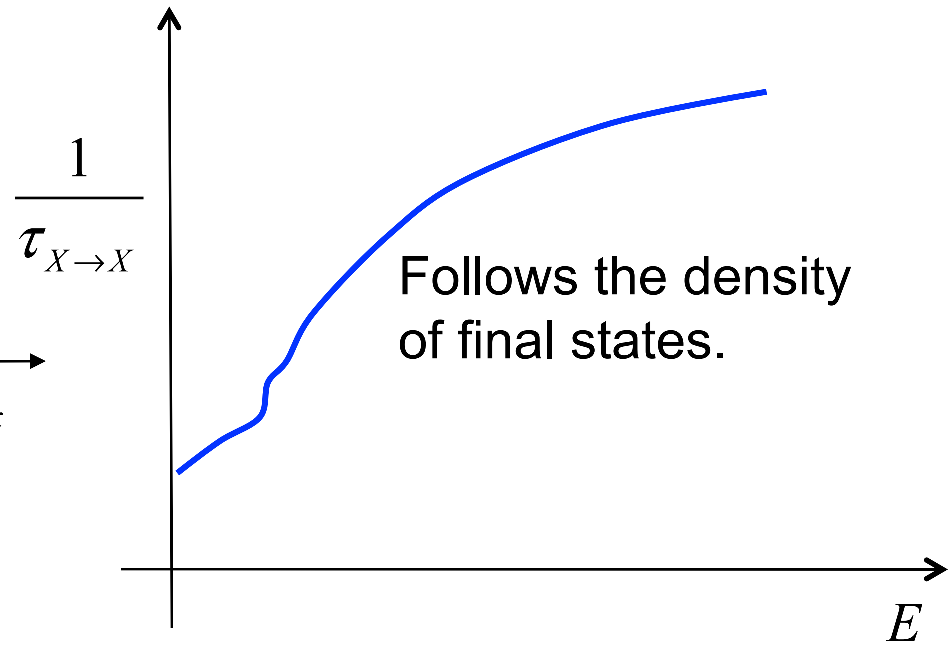
$m_l^* = 0.9 m_0$

$m_t^* = 0.19 m_0$

Equivalent IV scattering in Si

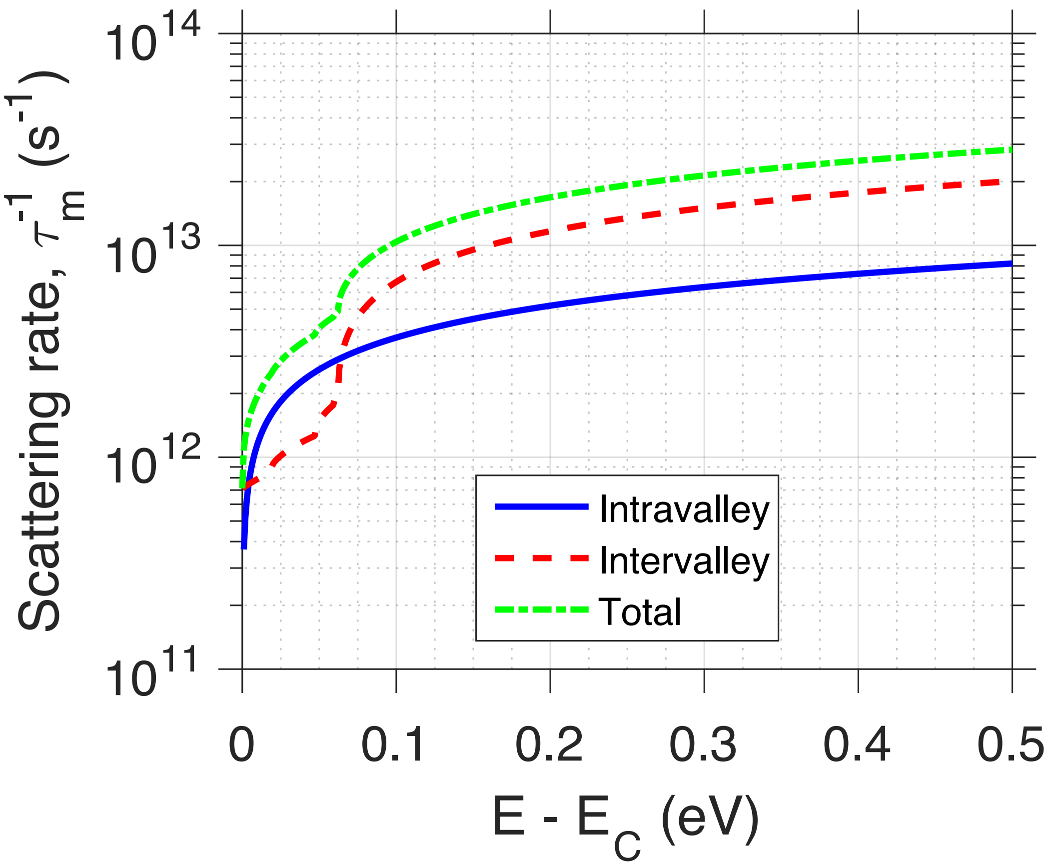
Si conduction band





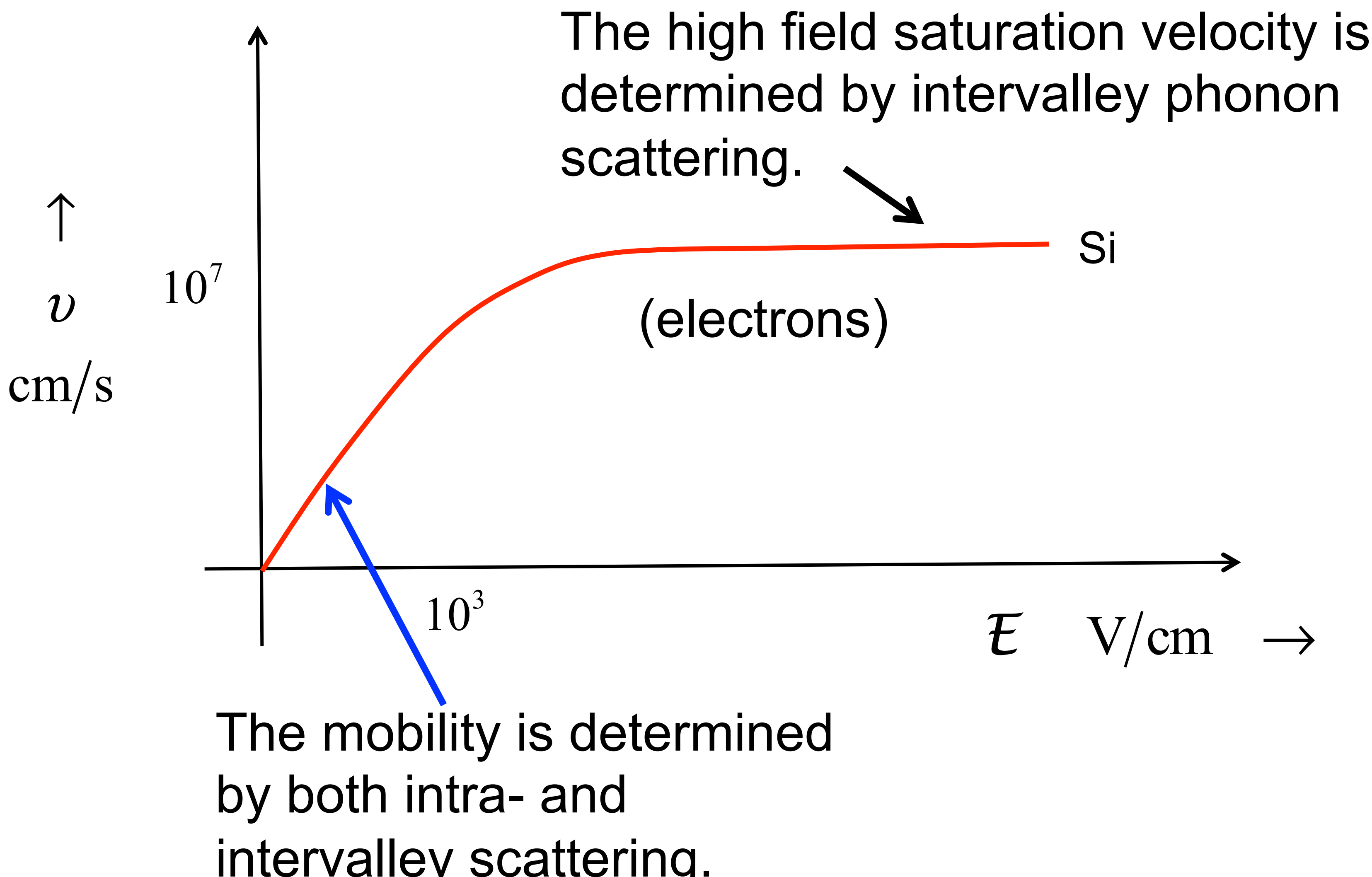
Important at room temperature in Si

Intra- vs. Inter-band scattering on n-Si



Calculations by J. Maassen, Dalhousie Univ. (2017) using parameters from Lino Reggiani, “General Theory,” Chapter 2 in *Hot Electron Transport in Semiconductors*, vol. 58 of Topics in Applied Physics, Springer-Verlag, New York, 1985. (Parameters were taken from Table 2.7.)

Velocity vs. electric field in bulk Si



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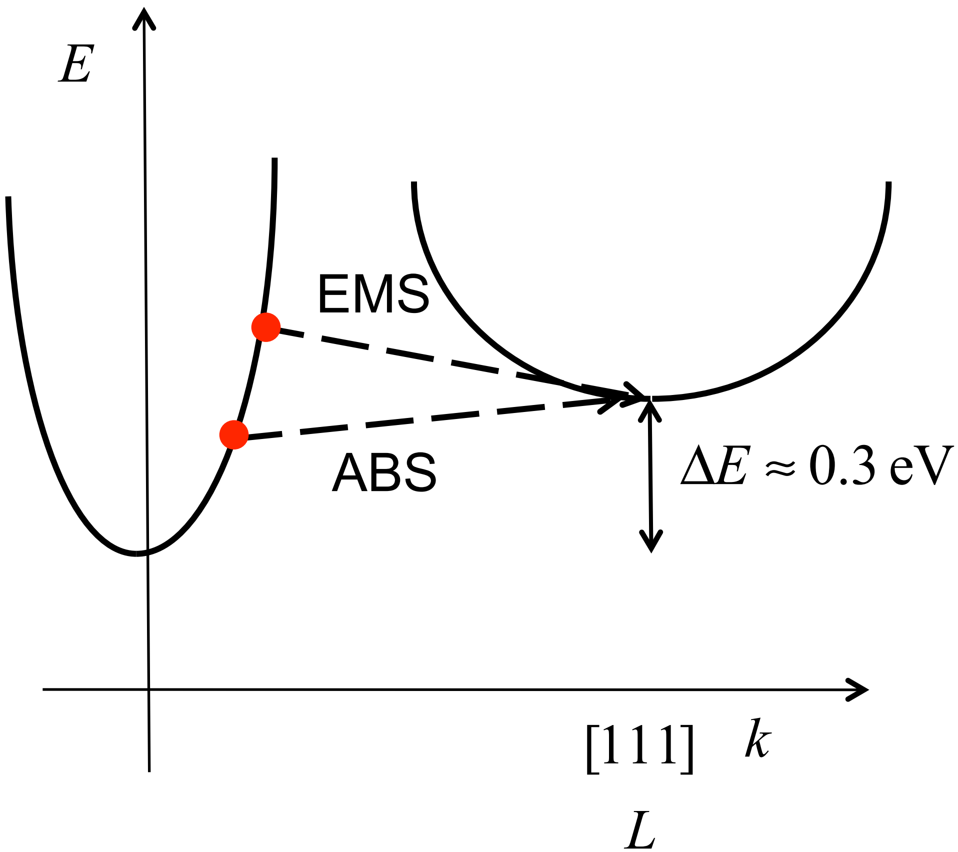
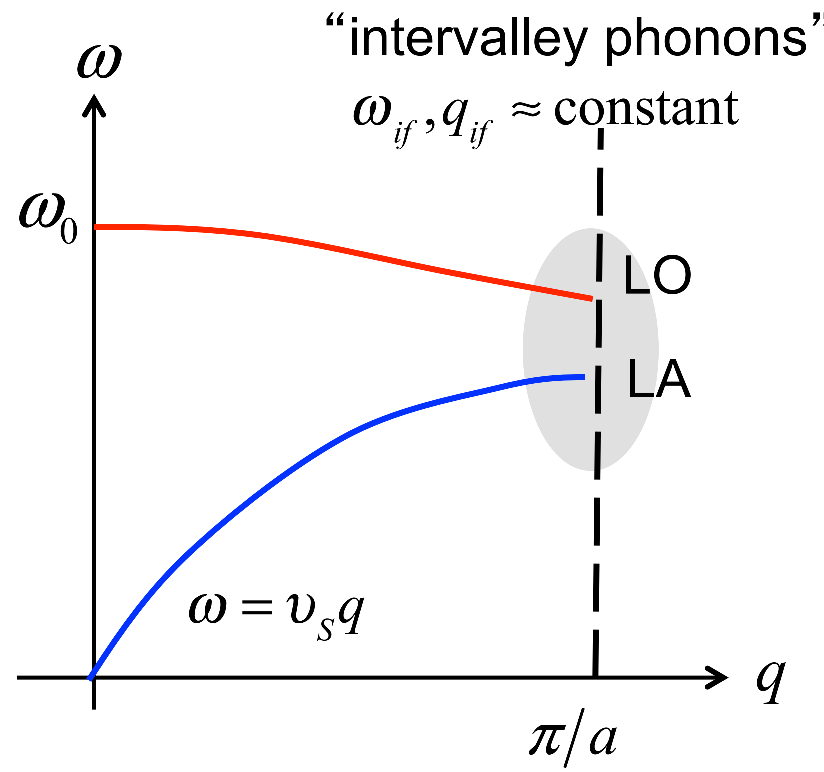
Transition rate





Requires phonons with momentum near the zone boundary.

Scattering times

Postulate:

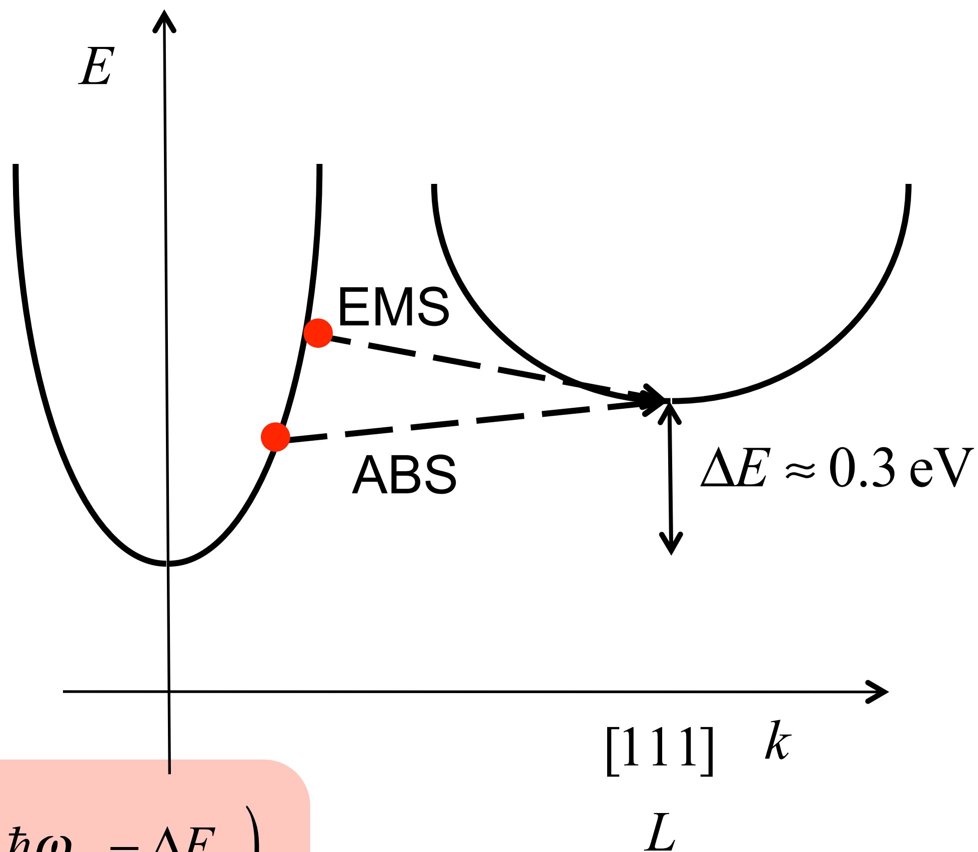
$$U_S = D_{if} u_\beta$$

Then IV scattering looks like ODP scattering

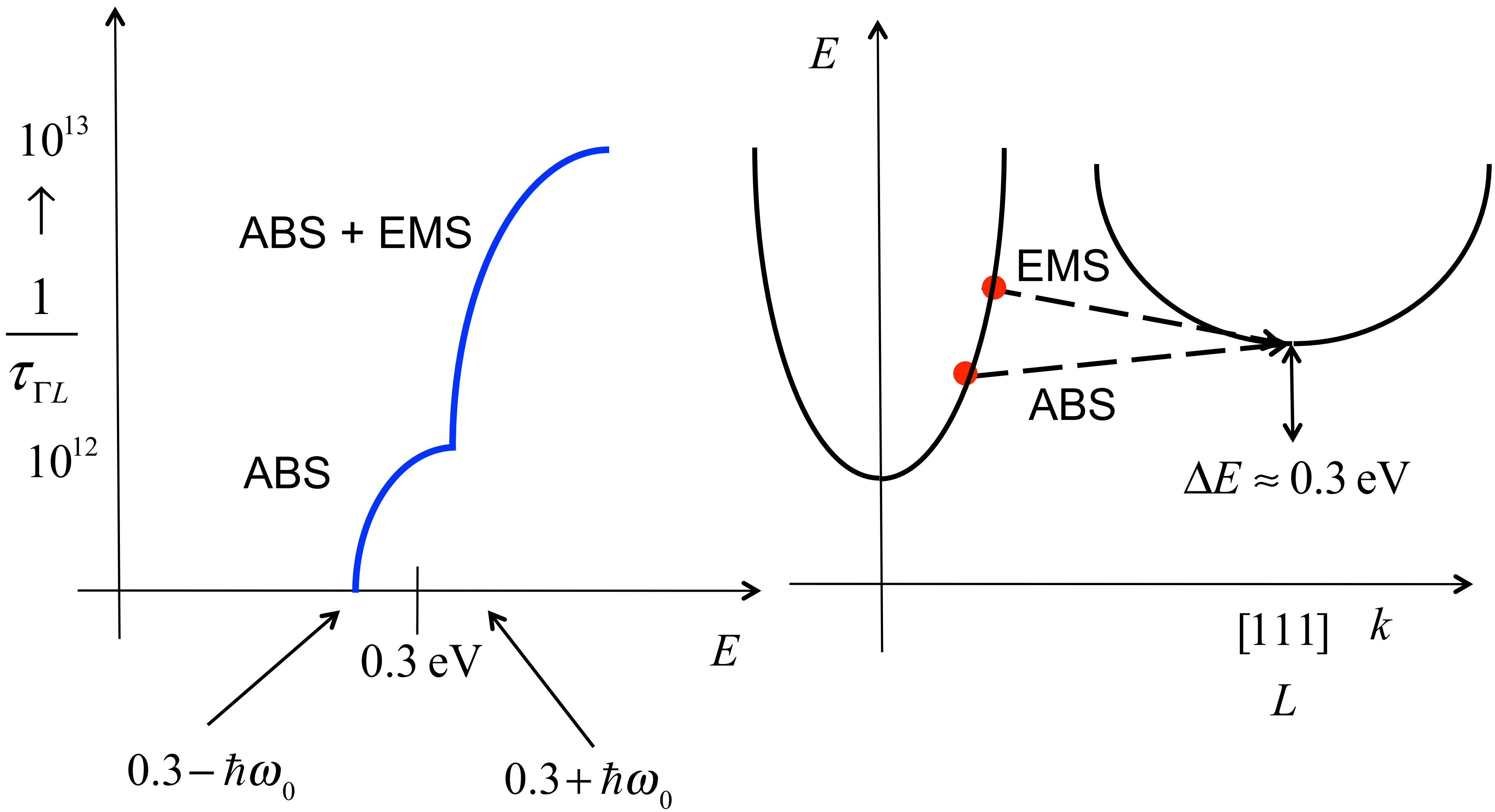
Isotropic: $\frac{1}{\tau} = \frac{1}{\tau_m}$

Number of final valleys: Z_f

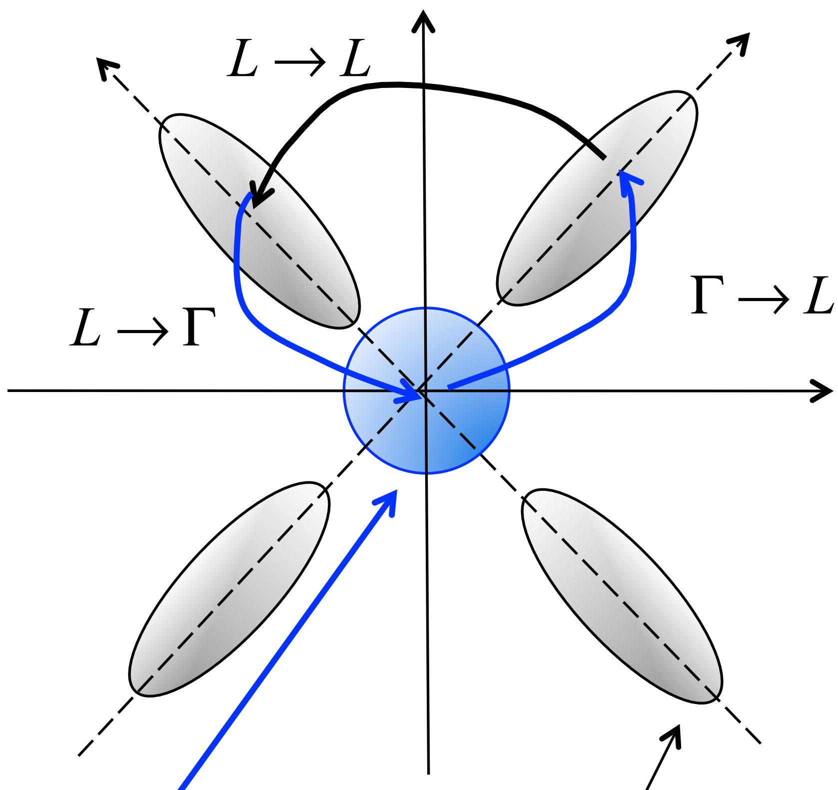
$$\frac{1}{\tau} = \frac{2\pi}{\hbar}\left(\frac{\hbar D_{if}^2 Z_f}{2\rho\omega_{if}}\right)\left(N_{if} + \frac{1}{2} \mp \frac{1}{2}\right)\frac{D_f\left(E \pm \hbar\omega_{if} - \Delta E_{fi}\right)}{2}$$



Scattering times



L-L and L-Γ IV scattering (GaAs)



$$\frac{1}{\tau} \propto D_{if}^2 Z_f \frac{D_f\left(E \pm \hbar\omega_{if} - \Delta E_{fi}\right)}{2}$$

$\Gamma \to L: \quad Z_f = 4 \quad \Delta E_{fi} = 0.3 \text{ eV}$

$L \to L: \quad Z_f = 3 \quad \Delta E_{fi} = 0 \text{ eV}$

$L \to \Gamma: \quad Z_f = 1 \quad \Delta E_{fi} = -0.3 \text{ eV}$

Compare rates:

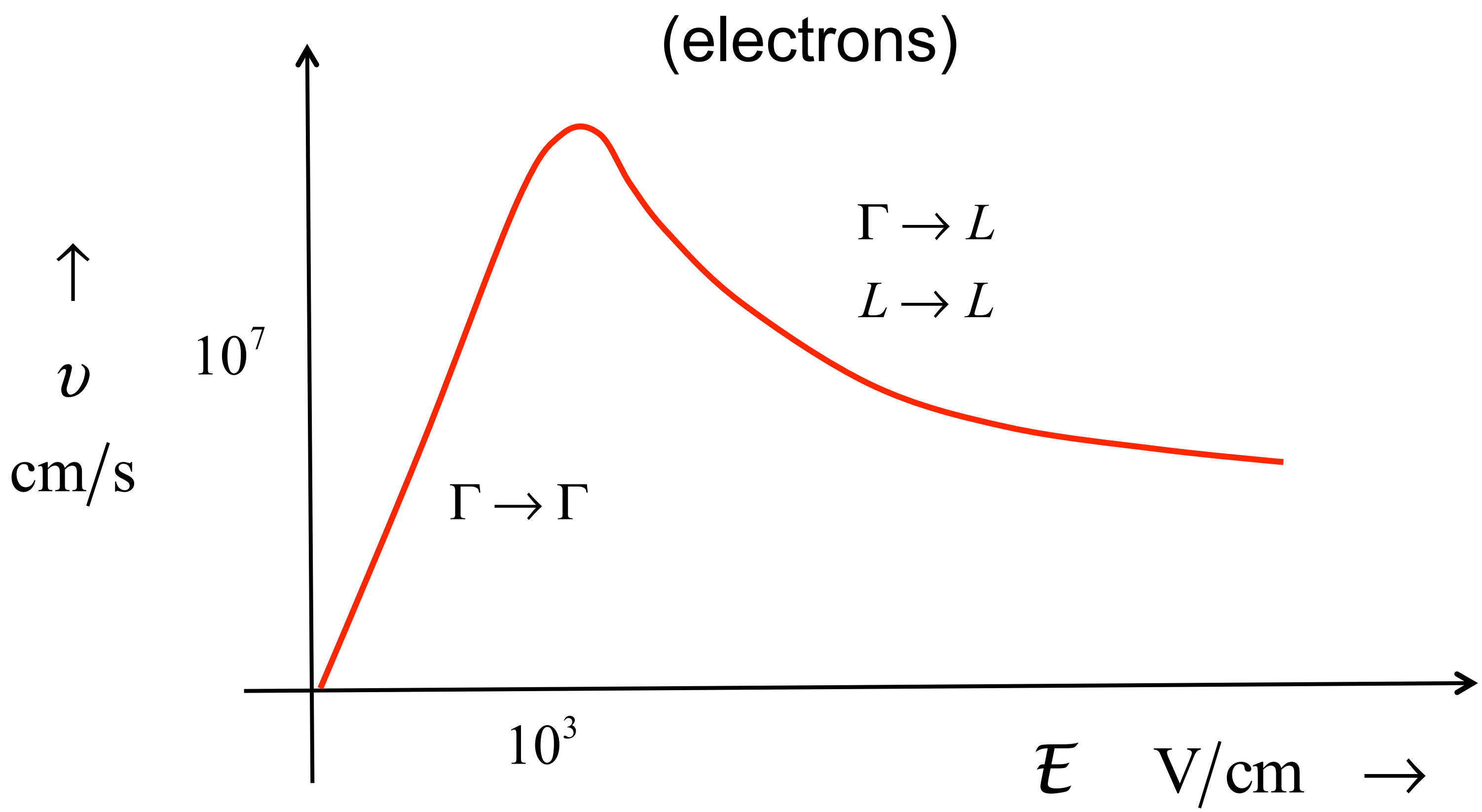
$1/\tau_{\Gamma \to \Gamma}$ (POP)

$1/\tau_{\Gamma \to L}$

$1/\tau_{L \to L}$

$1/\tau_{L \to \Gamma}$

Velocity vs. electric field in n-GaAs



Questions?

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