Band diagram, generation and recombination

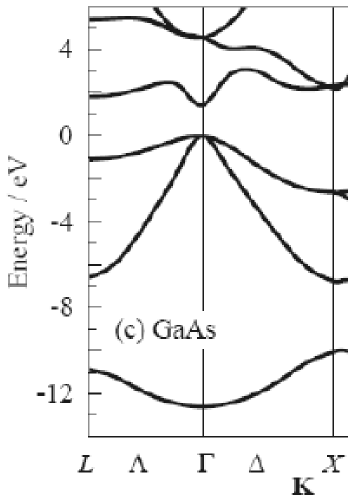
LECTURE 4

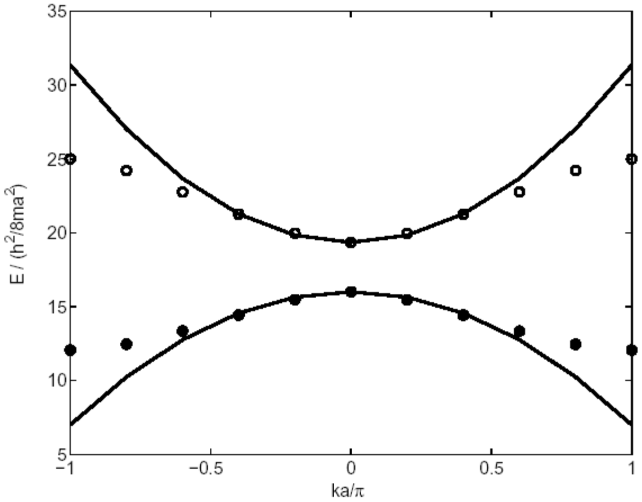
- Energy band diagram
- Phonons
- Thermal generation of electrons and holes
- Chemical generation (doping)
- R-G-centre recombination
- Minority carrier lifetime

Sec. 2.12

Potential energy

Microscopically:

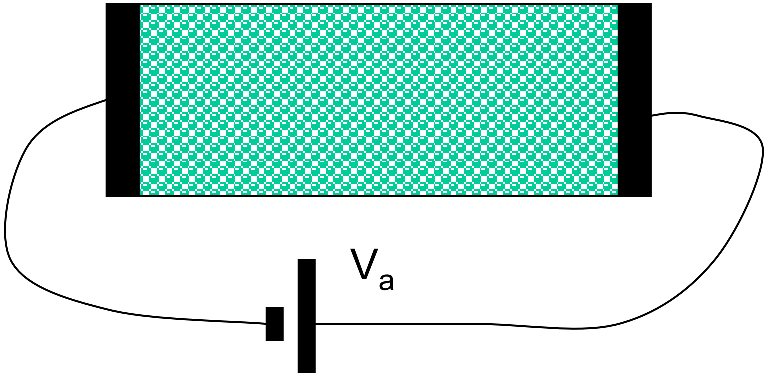




$$E_{CB}(k) = E_{C0} + \frac{\hbar^2 k^2}{2m^*}$$

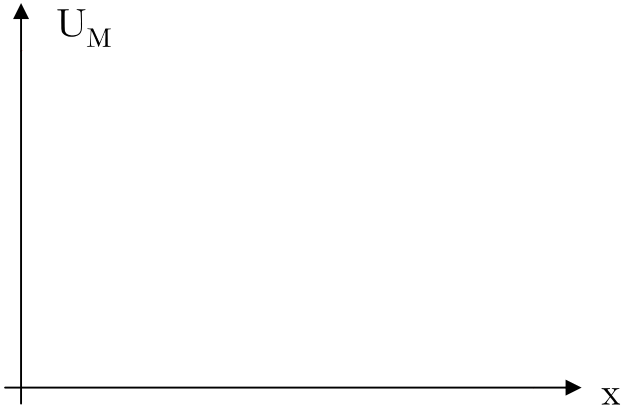
Physically, what is E_{C0} ?

Macroscopically:



What is $U_M(x)$?

Sketch it for this case.

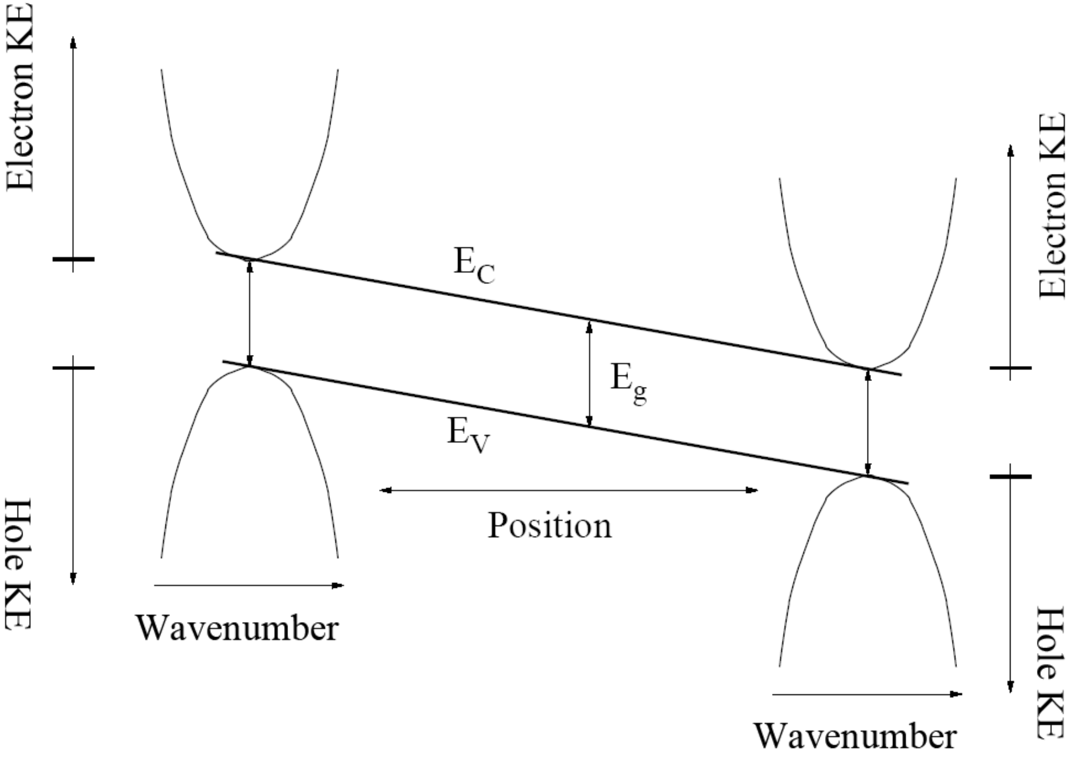


Sec. 2.12

Energy band diagram

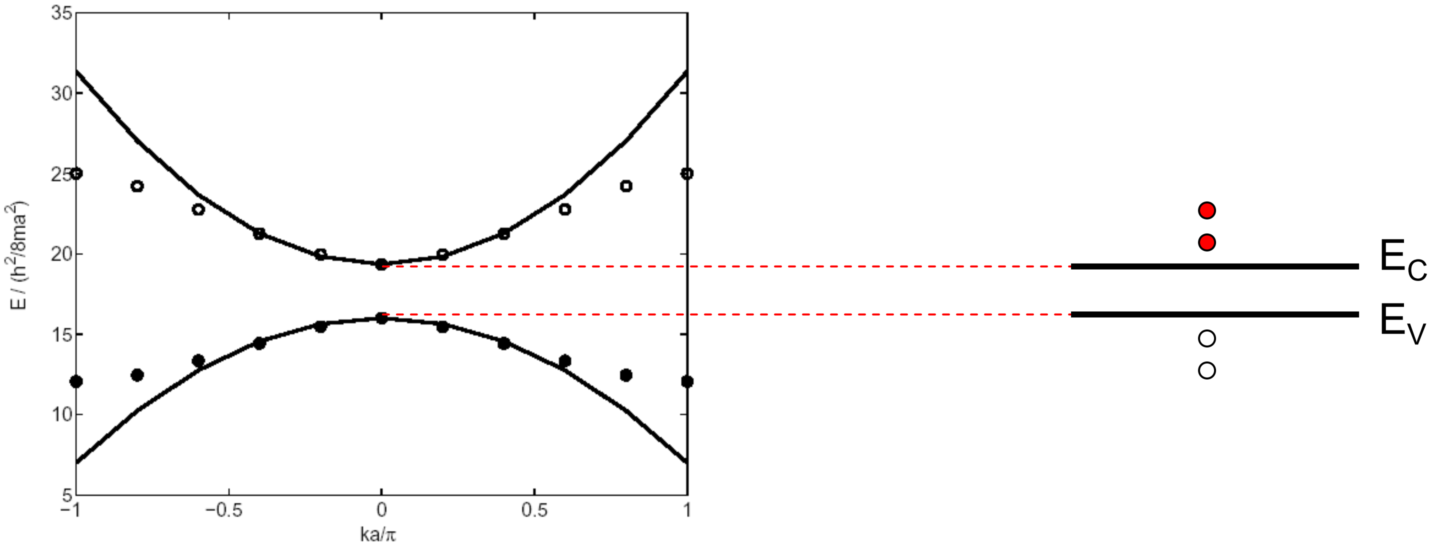
Add in the macroscopic potential energy

$$\begin{aligned} E &= U_M(x) + E_{C0} + \frac{\hbar^2 k^2}{2m^*} \\ &\equiv E_C(x) + \frac{\hbar^2 k^2}{2m^*}, \end{aligned}$$



Chap. 2

Key points from Chapter 2



- Electrons and holes reside in states
- Each state represents an energy and a crystal momentum
- Change in ħk is related to external forces
- ħk(E) ≡ in the parabolic-band approximation
- Each state identifies an allowable v(E) and KE

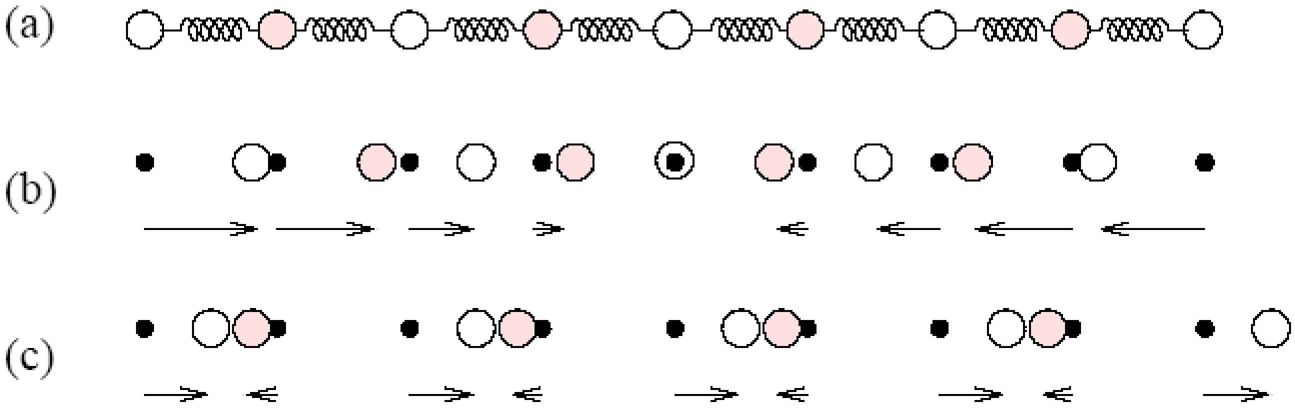
In the above energy band diagram, which is the faster electron and the faster hole?

Sec. 3.1.1

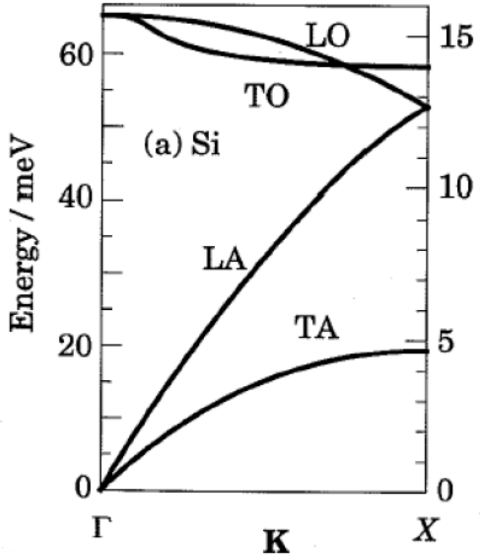
Phonons

The atoms of a lattice vibrate about their mean positions. The vibrations are coupled.

Representation of coupling via spring analogy



This leads to a dispersion relationship (Energy vs.)



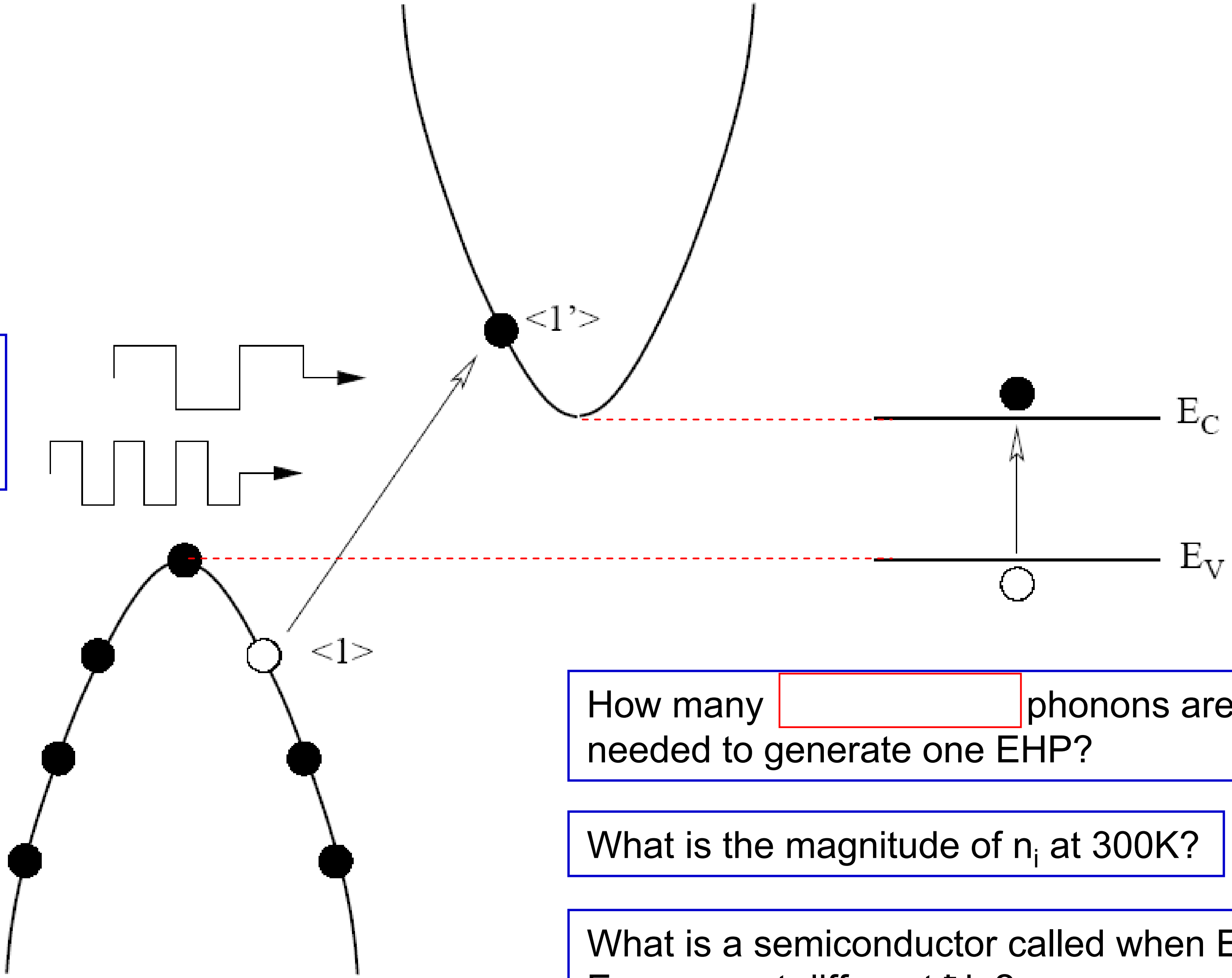
A quantum of lattice vibrational energy is called a

Note the range of phonon energies.

Which vibrational modes are shown in (b) and (c) above?

Sec. 3.1.1

Thermal generation of EHP's



What are these `waves'?

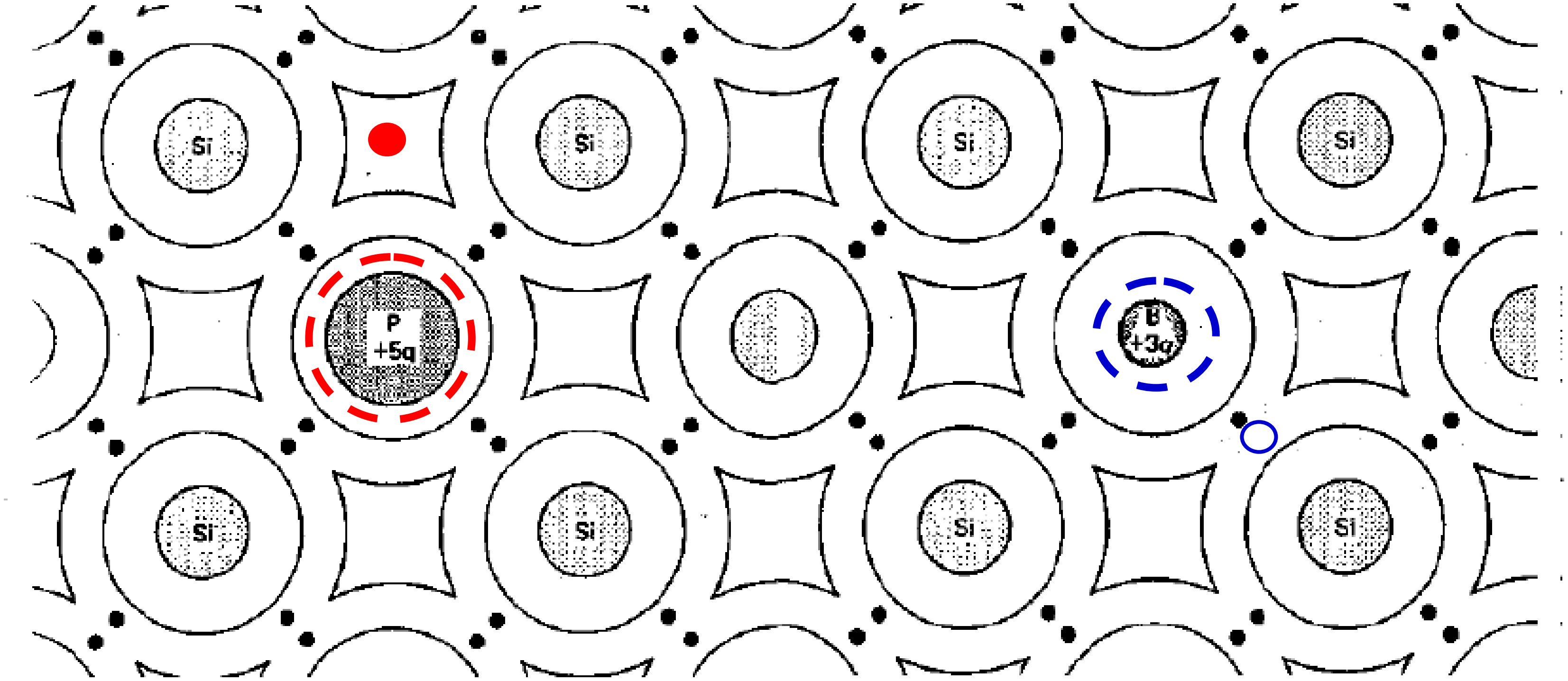
How many phonons are needed to generate one EHP?

What is the magnitude of n_i at 300K?

What is a semiconductor called when E_{C0} and E_{V0} occur at different ħk ?

Chemical generation of electrons or holes

Sec. 3.1.4



Doping is the incorporation in the lattice of selected dopant atoms.

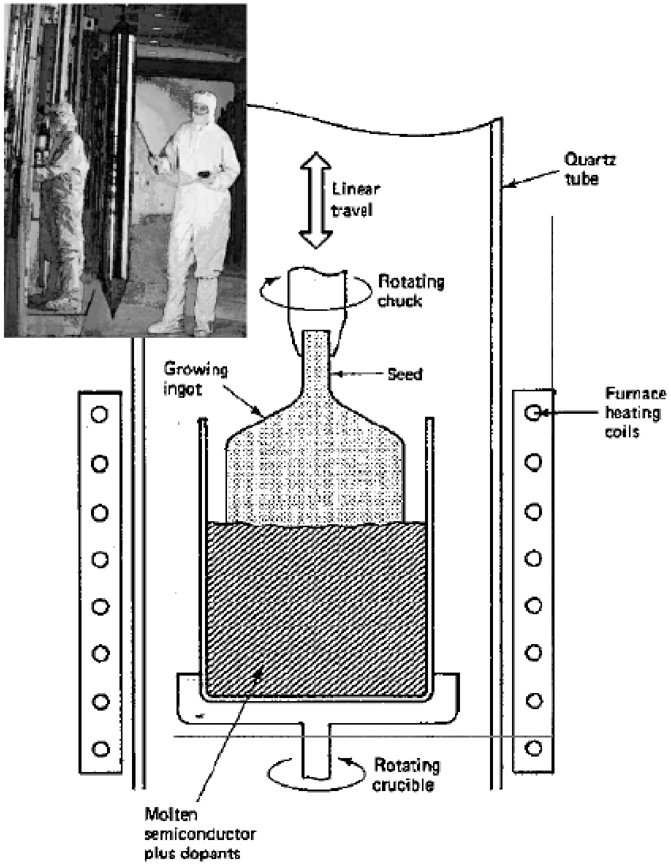
Important vocabulary:

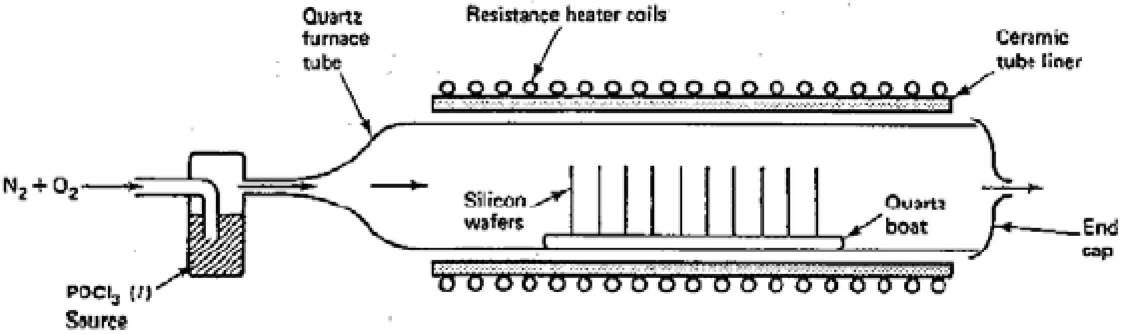
Typically, doping densities are cm^{-3}.

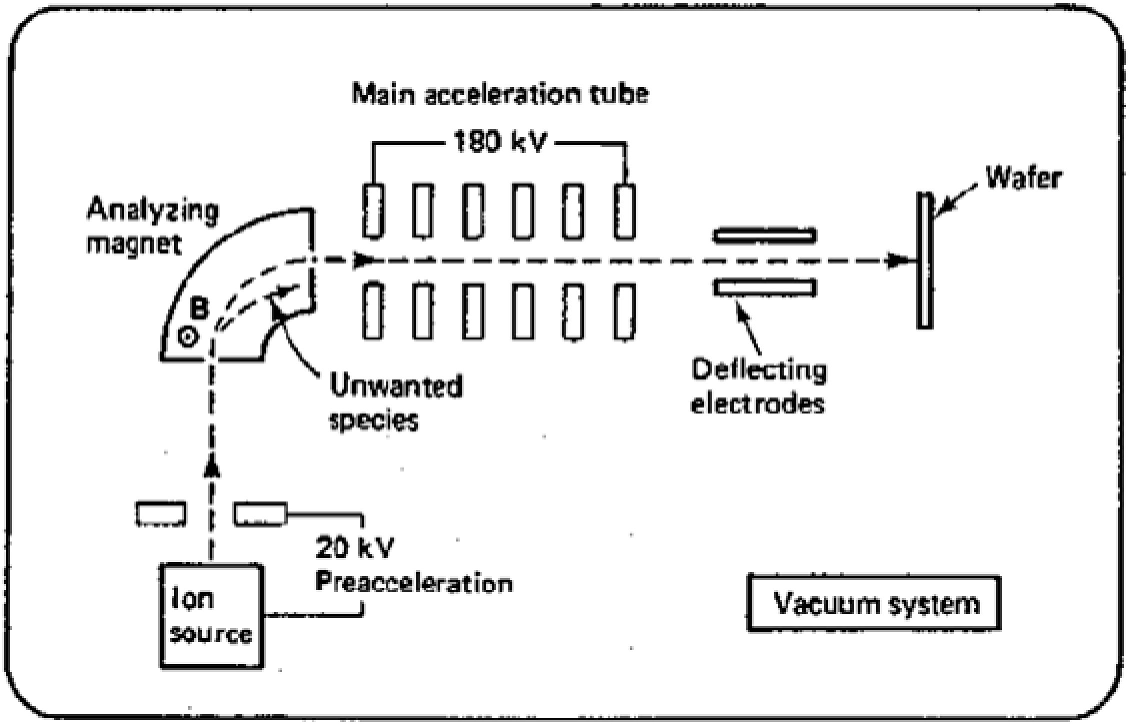
How many ppm is this?

Sec. 3.1.4

Doping Semiconductors



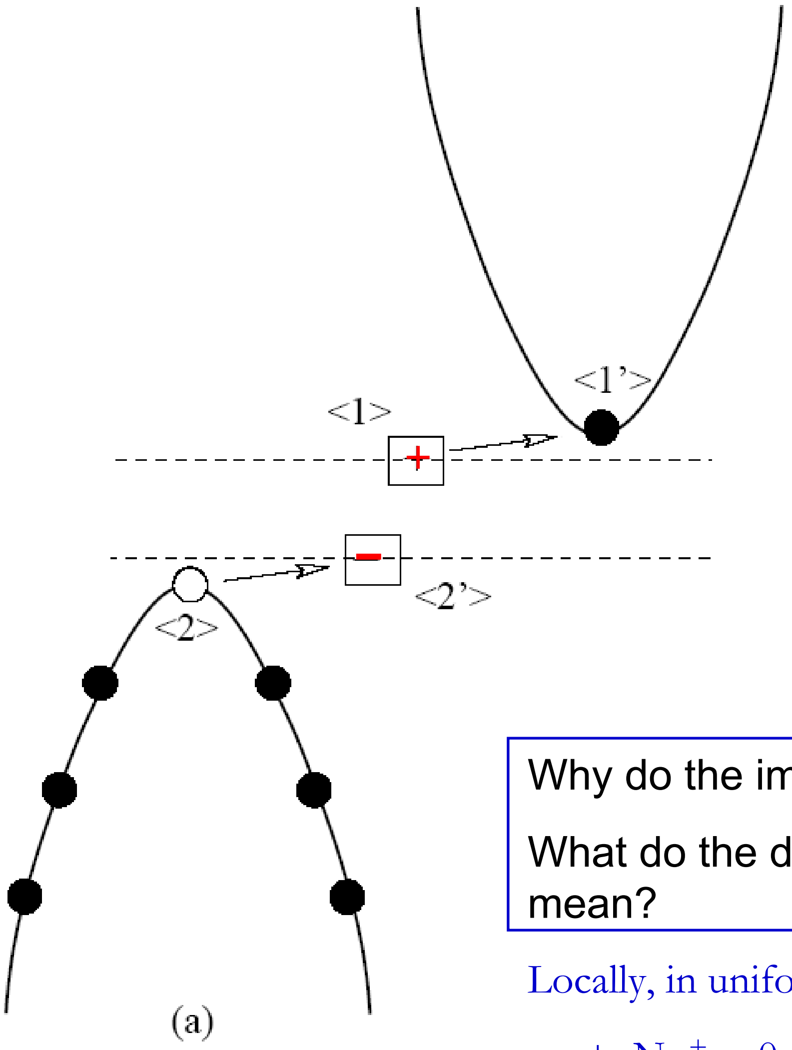


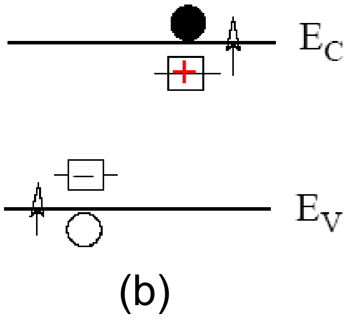


What are all these processes called?

Sec. 3.1.4

Extrinsic carrier generation





Why do the impurity atoms not form energy bands?

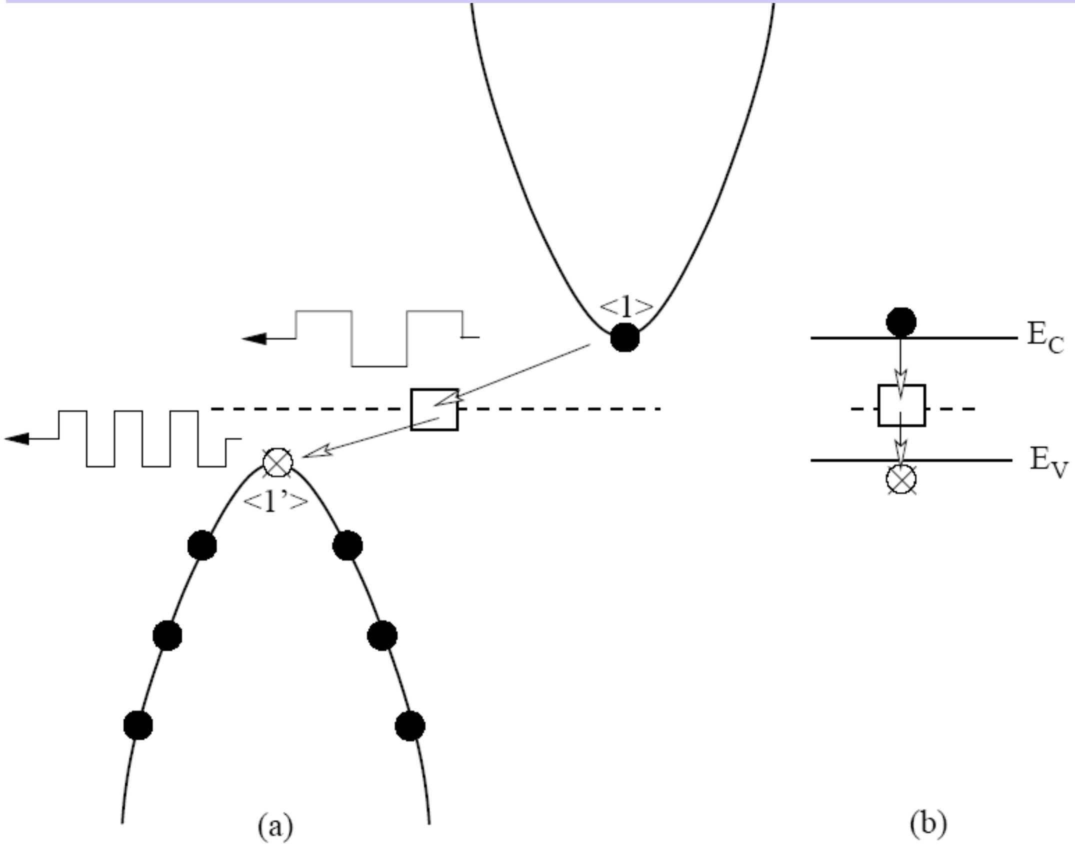
What do the dashed lines in (a) and the short lines in (b) mean?

Locally, in uniformly-doped material, with $N_D, N_A > n_i$:

$-qn+qN_D^+ = 0$ or

Sec. 3.2.2

R-G-centre recombination



What is the box in the bandgap?

Why are the phonon arrows pointing outward?

Rate of recombination for p-type material: ⟶ $R_{RG,} \approx r N_T n \equiv$

Another name for this type of recombination is

Sec. 3.2.2

Generation and recombination via R-G centres

For p-type material: $R_{RG} = An$ $G_{RG,th} = An_0$

Net rate of R-G-centre recombination: $U = R – R_0 \equiv R - G_{th,0}$

How does n differ from n_0 ?

What are the units of U?

Secs.
3.2.4, 4.1

Thermal equilibrium

Two conditions need to be satisfied:

1. No net rate of recombination $U = R - G_{th} = 0$

e.g., for R-G-centre recombination in ☐ material

$$R - G = A(n_0 + \Delta n) - An_0$$

$$= A\Delta n \equiv \frac{\Delta n}{\tau} \longrightarrow \tau_{e,\mathrm{RG}} = \frac{1}{A}$$

i.e., $\Delta n =$ ☐ in equilibrium

What is τ called?

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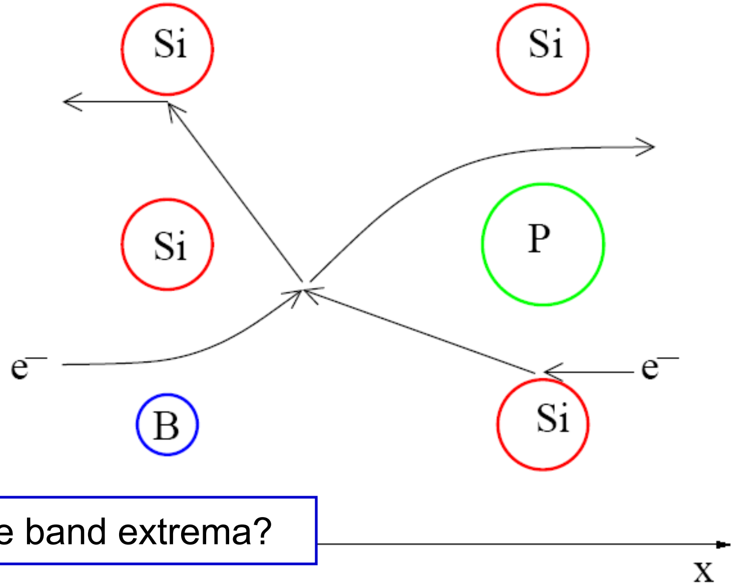
2. Collisions randomize a carrier's momentum

What's another verb for `collide'?

Collisions keep electrons and holes near the ☐



Now do you see the usefulness of a parabolic fit to the band extrema?