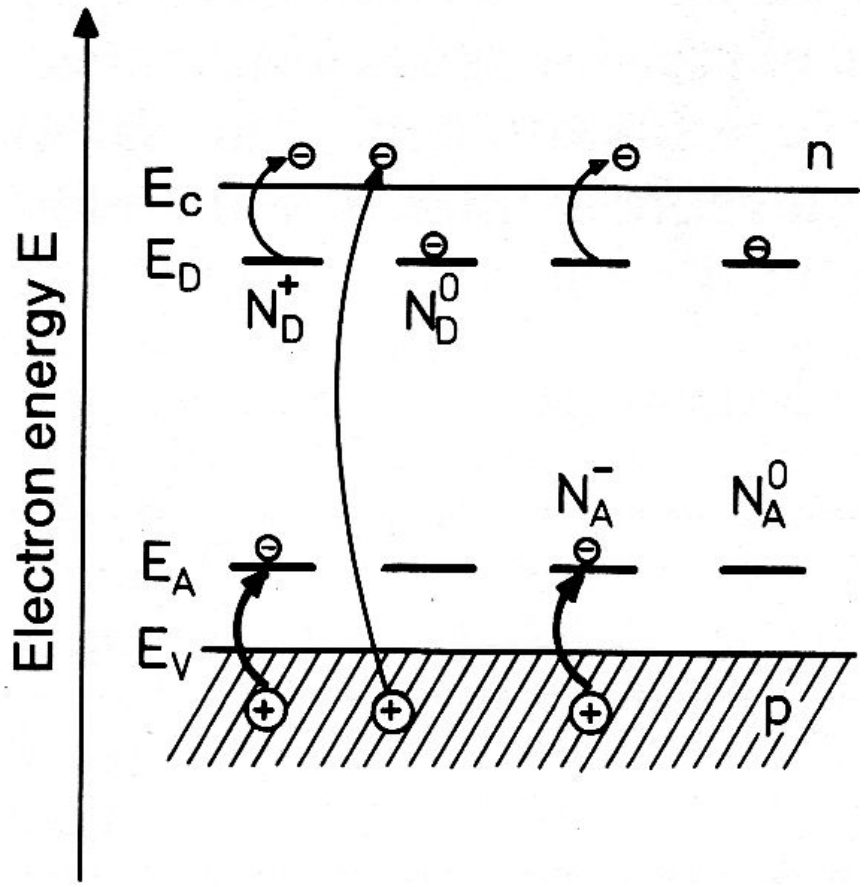
# Ladungsträgerstatistik

## extrinsischer Fall




Konzentrationen:

Donatoren sind neutral oder ionisiert:

$$N_D = N^0_D + N^+_D$$

Akzeptoren sind neutral oder ionisiert:

$$N_A = N^0_A + N^-_A$$

Neutralität: $n + N^-_A = p + N^+_D$

mit $e^-$ besetzte Donatoren:

$$N^0_D = N_D \left( 1 + \exp\left( (E_D - \mu)/k_B T \right) \right)^{-1}$$

mit $h^+$ besetzte Akzeptoren:

$$N^0_A = N_A \left( 1 + \exp\left( (\mu - E_A)/k_B T \right) \right)^{-1}$$

Nun für gegebene $N_A$, $N_D$ $\mu$ so variieren, dass alle Gleichungen erfüllt

hier nur Spezialfall:

| | | |
|---|---|---|
| n-Typ | d. h. $N_A = 0$ | (oder $N_D \gg N_A$) |
| extrinsischer Bereich | d. h. $N^+_D \gg n_i$ | (also kleine $T$) |

folglich $n \approx N^+_D$

Tafel

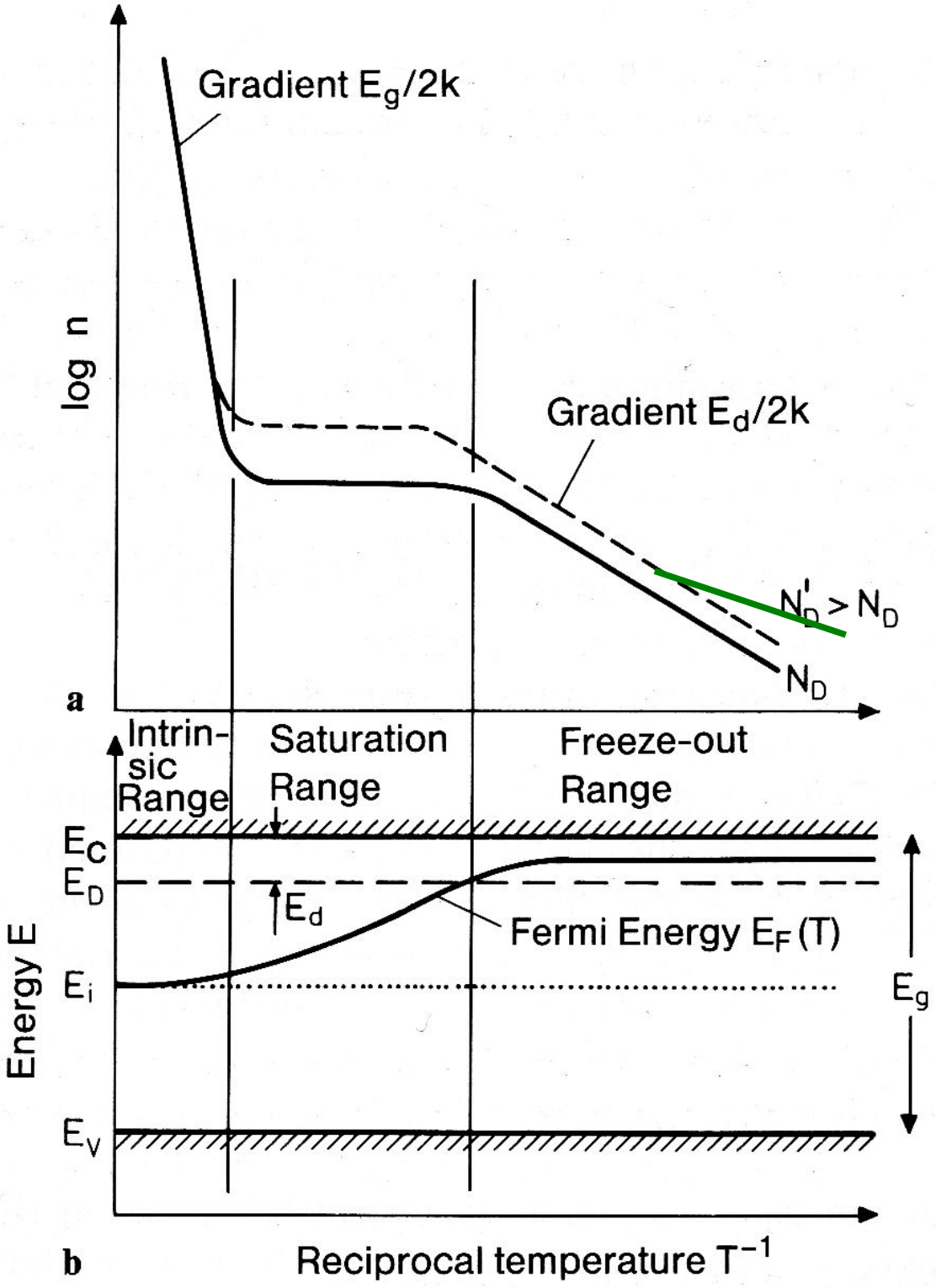



Fig.12.10a Ibach-Lüth

**Conduction band e⁻ concentration *n***

of *n* type semiconductor

for two donor concentrations $N'_D > N_D$

$E_g$: width of the forbidden band

$E_d$: ionization energy of the donors

**Fermi energy $E_F(T)$**

$E_C$: lower conduction band edge

$E_V$: upper valence band edge

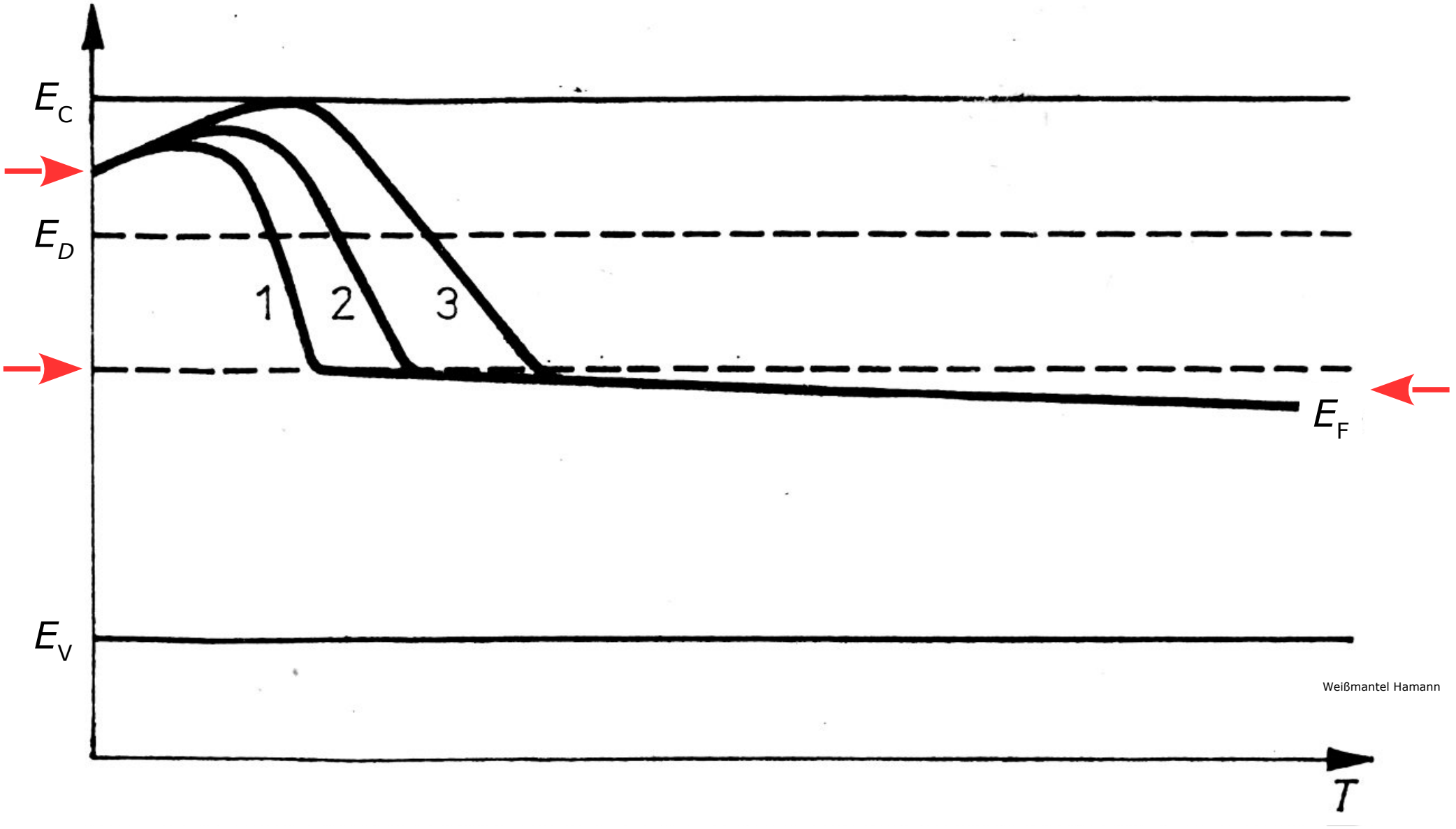
$E_i$: Fermi level of intrinsic semiconductor

Very low T:

Overlapping impurity states cause band

Conductivity of impurity band

# Abhängigkeit des Fermi-Niveaus von der Temperatur bei einem $n$-Halbleiter




Weißmantel Hamann

**Dotierung: 1 $\triangleq N_{D1}$; 2 $\triangleq N_{D2}$; 3 $\triangleq N_{D3}$; $N_{D1} < N_{D2} < N_{D3}$**



Tafel: MWG

Only Ge is clean enough.

Fig. 12.11 Ibach-Lüth

**Electron concentration *n*** in n-type Ge

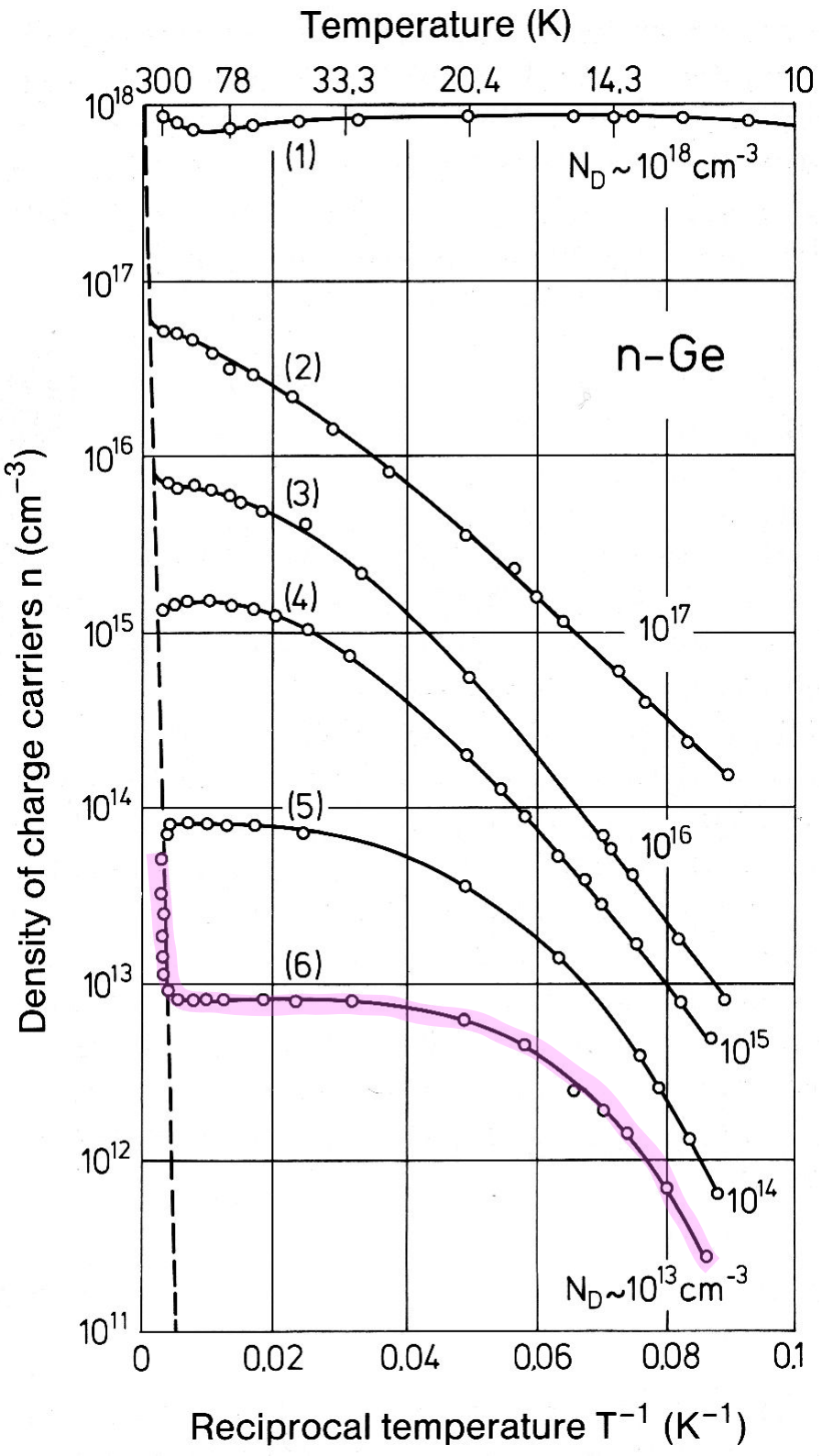
Hall effect data

Donor concentration $N_D$ varies

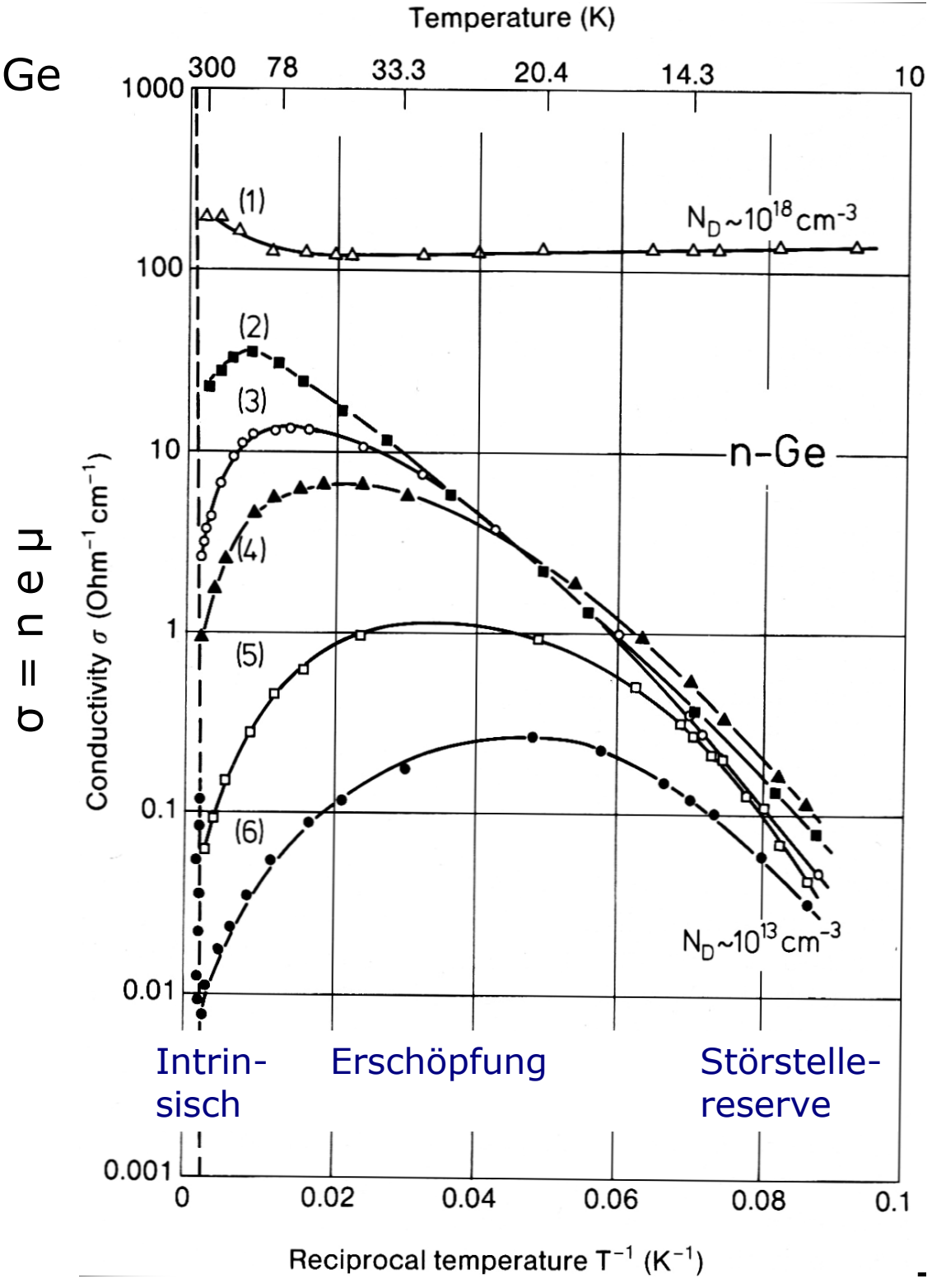
$10^{18}$ ... $10^{13}$ $cm^{-3}$ for samples 1 ... 6

*T* dependence in intrinsic region

shown by dashed line



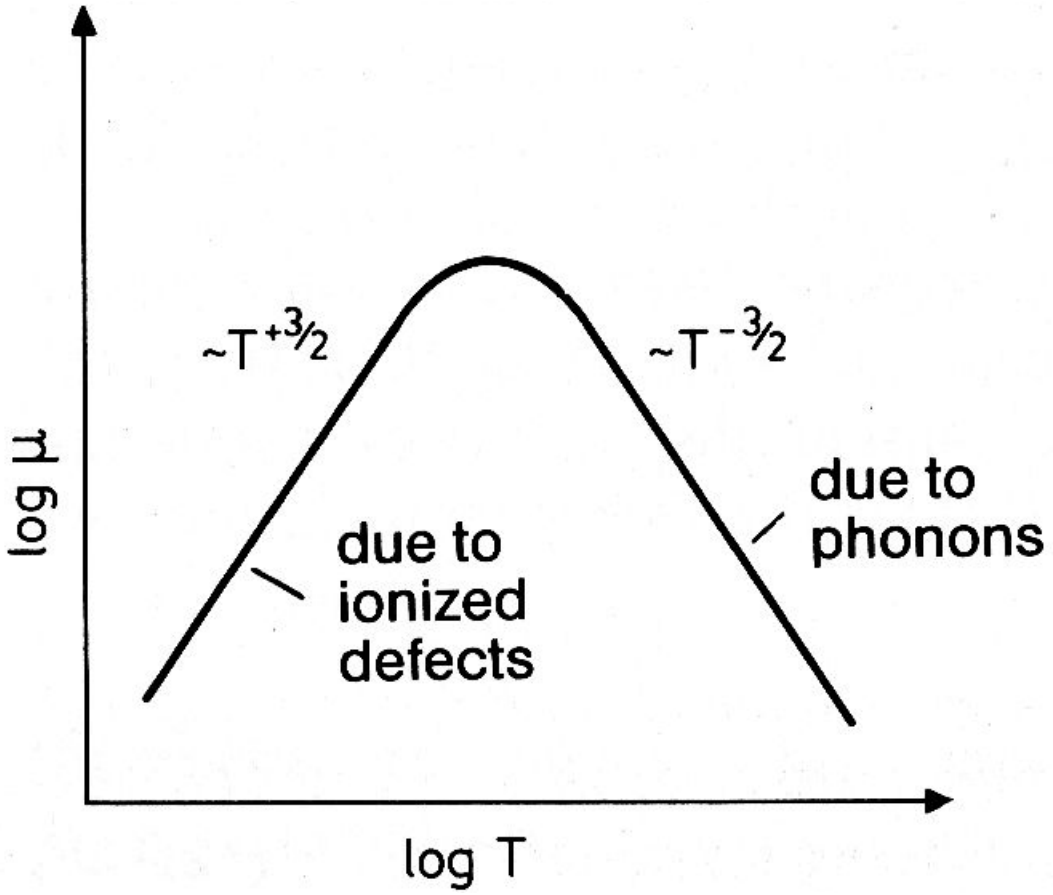
**Conductivity** of n-type Ge




increasing $N_D$

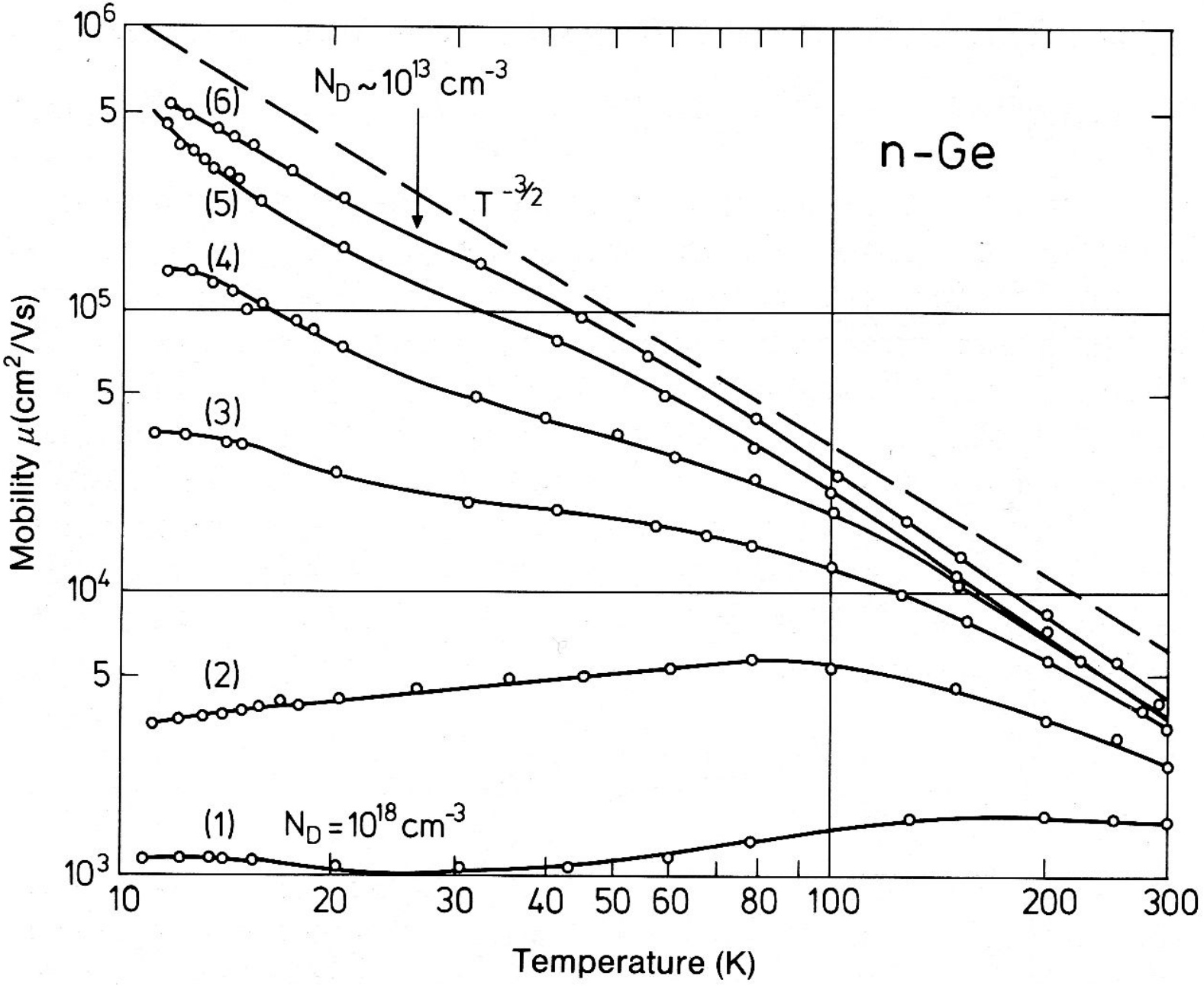
# Schematic **Mobility $\mu(T)$**



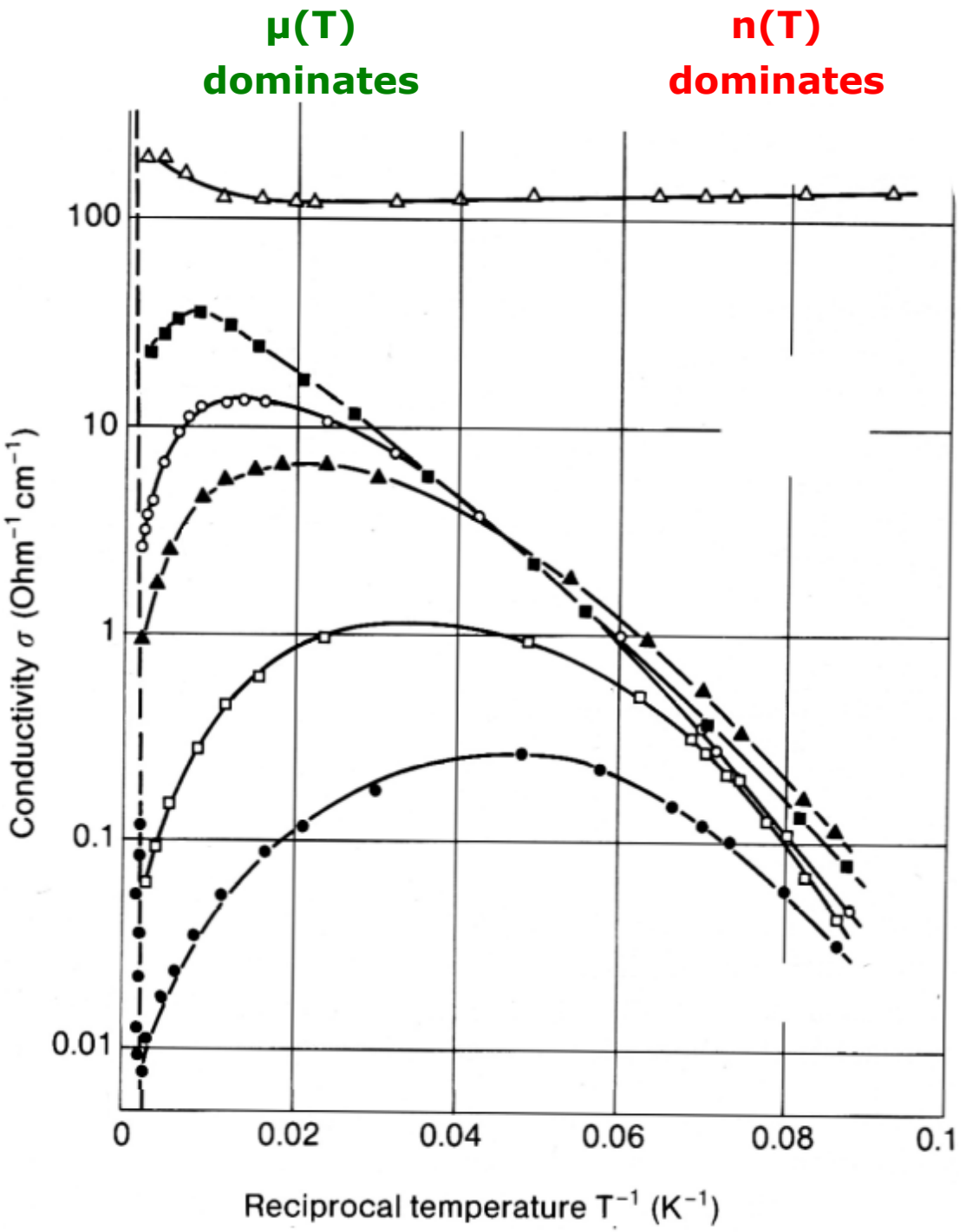


# Experimental **Mobility $\mu(T)$**

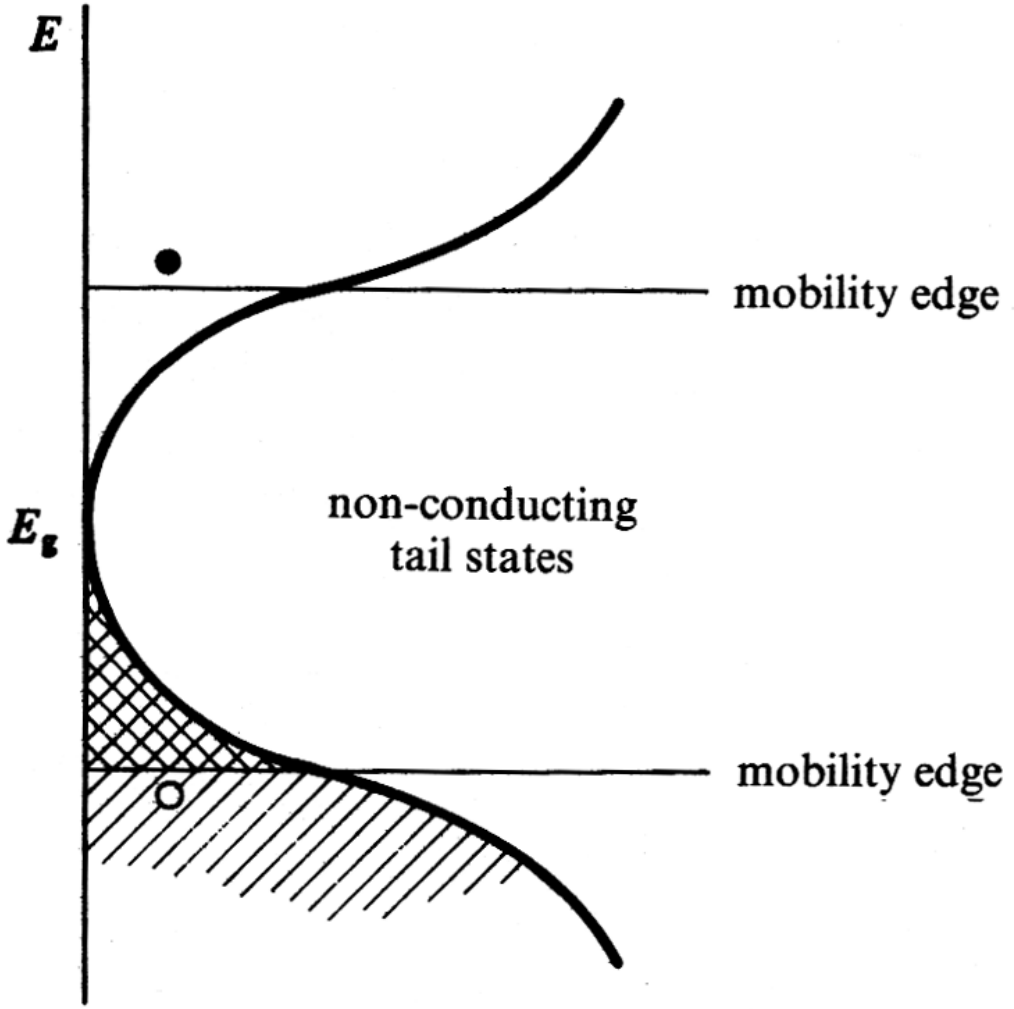




$\sigma = n e \mu$


μ(T)
dominates
n(T)
dominates
100
10
1
0.1
0.01
0
0.02
0.04
0.06
0.08
0.1
Conductivity σ (Ohm⁻¹ cm⁻¹)
Reciprocal temperature T⁻¹ (K⁻¹)

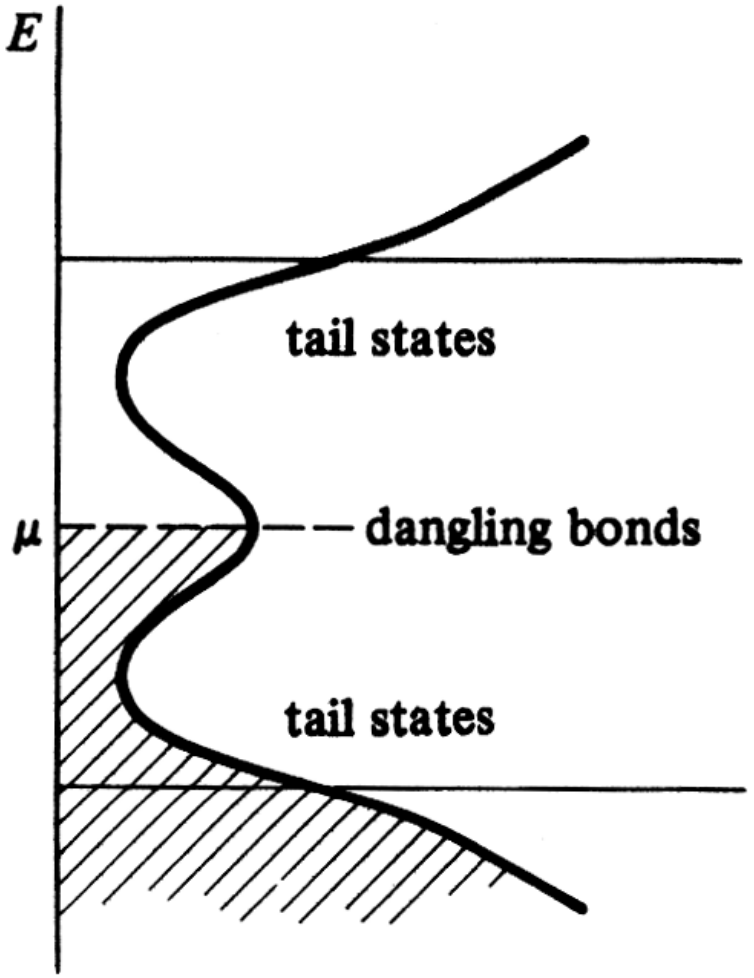
# Einfluss von Unordnung




10.16 Marder

In a fully coordinated but distorted tetrahedral semiconductor like Si, disorder causes a spread of the levels into the region of the energy gap of the perfect crystal. These so-called tail states arise from the distorted bonds and are considered to be localized and non-conducting. The energy gap is replaced by a mobility gap.

# Amorpher Halbleiter (preisgünstige Solarzellen)




10.17 Marder

In practice an amorphous semiconductor contains imperfectly coordinated atoms, leading to uncompensated or 'dangling' bonds. Each such bond produces a localized electron and a localized empty state. On account of their quasi-atomic character, these states are concentrated about the middle of the energy gap; they are sufficiently numerous to lock $E_F$ at 1/2 $E_g$. As a consequence, the amorphous semiconductor becomes insensitive to doping.