Condensed Matter Physics I

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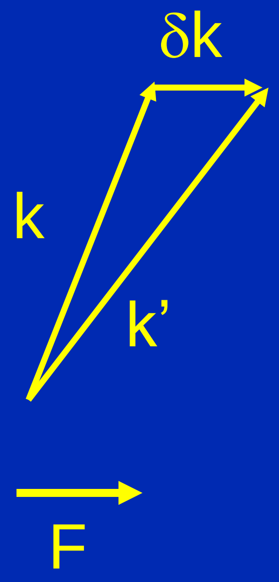
Previously

- Free electron model
- Density of states, Fermi-Dirac distribution
- Pressure, Bulk modulus, Heat capacity, Thermal mass

Today

- Transport
- Failures of the free electron model
- Incorporating periodicity

Electrical conductivity



2nd Newton: $m\frac{dv}{dt} = F$ or $\delta k = \frac{1}{\hbar}\int F dt$

Relaxation time τ: $\delta k \rightarrow 0$

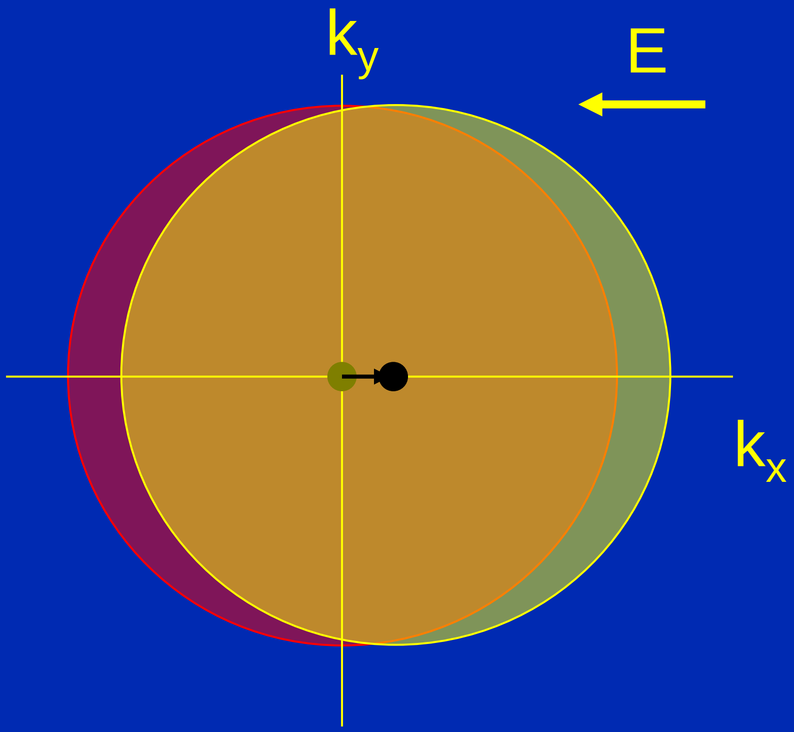
e-p,e-e scattering (appendix J, Ch. 10)
Impurity scattering

$$\delta k = \frac{1}{\hbar} F\tau$$

Equation of motion:

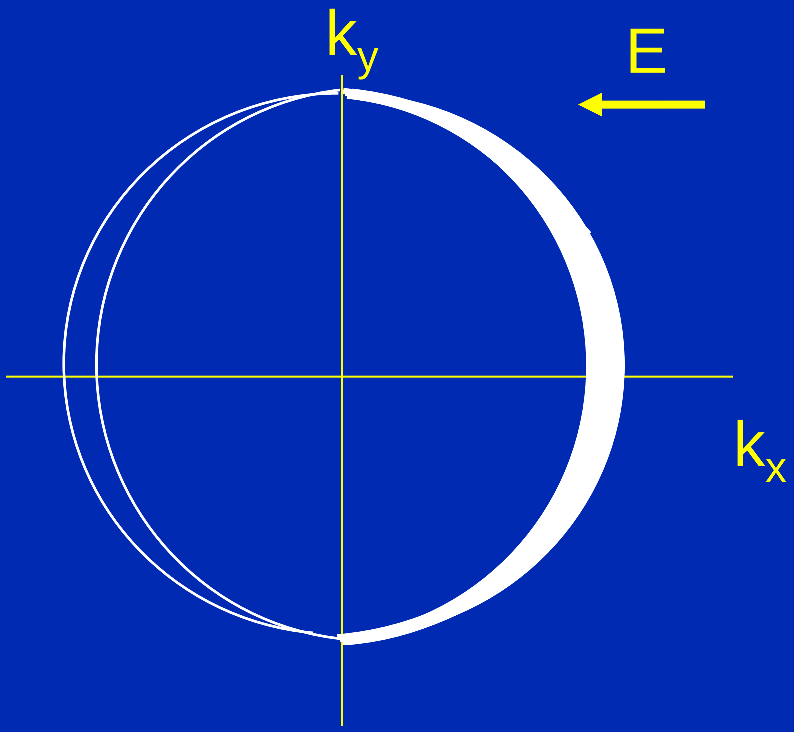
$$\hbar\left(\frac{d}{dt} + \frac{1}{\tau}\right)k = F$$

Electrical conductivity



$$\delta k = \frac{1}{\hbar} F\tau$$

Electrical conductivity



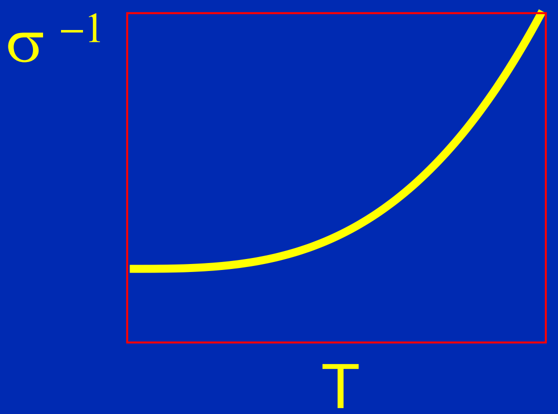
$$\delta k = \frac{1}{\hbar} F \tau$$

Ohm's law

$$\delta k = \frac{1}{\hbar} F\tau$$

$$\delta k = \frac{qE\tau}{\hbar}; \qquad v_{drift} = \delta v = \frac{qE\tau}{m}$$

$$F = qE$$

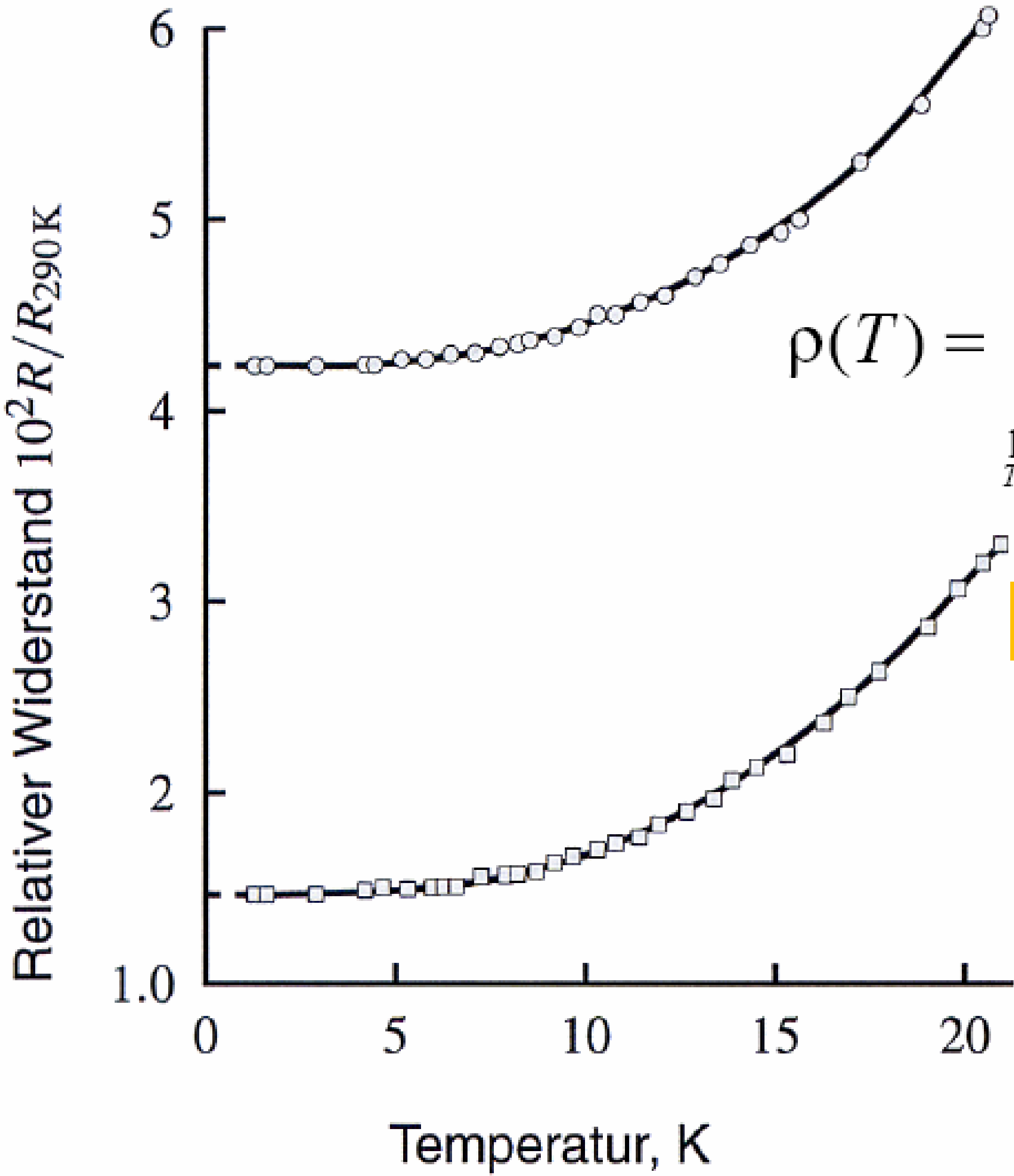


Current density $$j = nq\delta v = \frac{ne^2\tau E}{m}$$

Ohm's law $$\sigma = \frac{j}{E} = \frac{ne^2\tau}{m}$$

$$\left.\begin{array}{l}\sigma \sim 10^7\ \Omega^{-1}m^{-1} \\ n \sim 10^{28}\ m^{-3}\end{array}\right\} \quad \tau \sim 10\,fs \quad \Rightarrow \quad \ell = v_F\tau \sim 10\,nm$$

Very pure metals, low T: $\ell > 1\,cm$!!



Resistance of potassium at 20 K for two different samples.

$$\rho(T) = \underbrace{\rho_{Ph}(T)}_{\lim_{T\to 0}\rho_{Ph}(T)=0} + \underbrace{\rho_i(T)}_{\lim_{T\to 0}\rho_i(T)=\rho_i(0)}$$

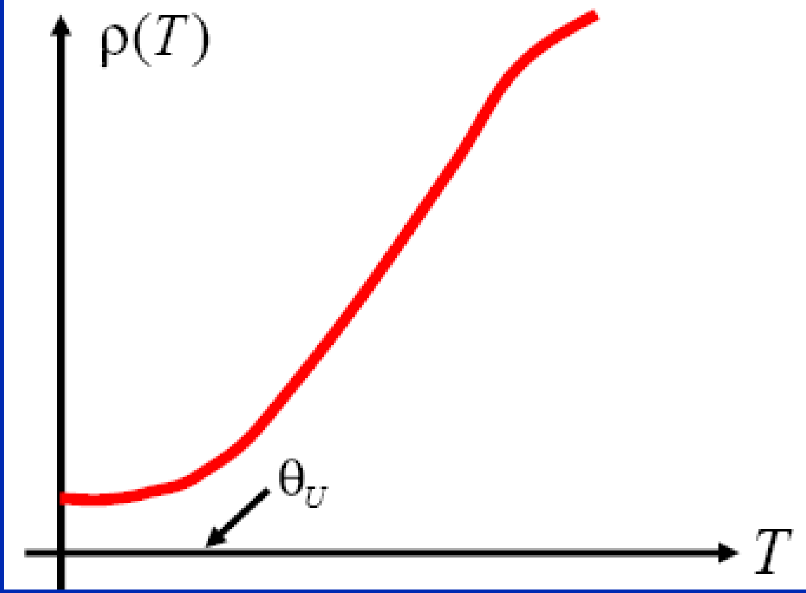
Residual resistance ration RRR

$$\frac{\rho(T=293\ \mathrm{K})}{\rho(T=0\ \mathrm{K})} = 1.1\ldots1000$$

An impurity causes a residual resistance of:

$1\cdot 10^{-6}\,\Omega\mathrm{cm}$ pro Atomprozent der Verunreinigung.

Temperature dependence of the electric resistance



(1) Very low temperatures

$\rho_{Phonon} \propto T^5 / \Theta_D^5$

Umklapp-processes are not possible for T<2K in the case of K

(2) Low temperatures

Umklapp-processes become possible

$\langle n \rangle \propto e^{-\Theta_U/T}$ characteristic Umklapp-temperature

Potassium: Θ_U=23K; Θ_D=91K

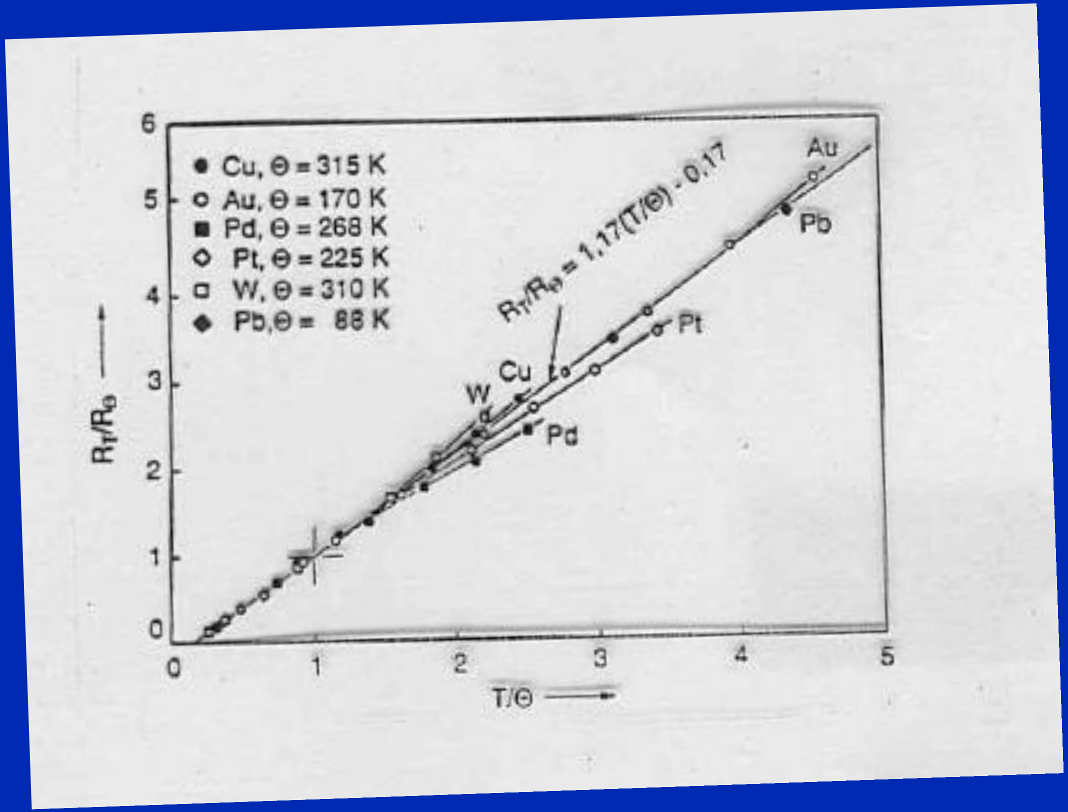
(3) High temperatures

$\langle n \rangle \propto T$ ➔ $\rho_{Phonon} \propto T$

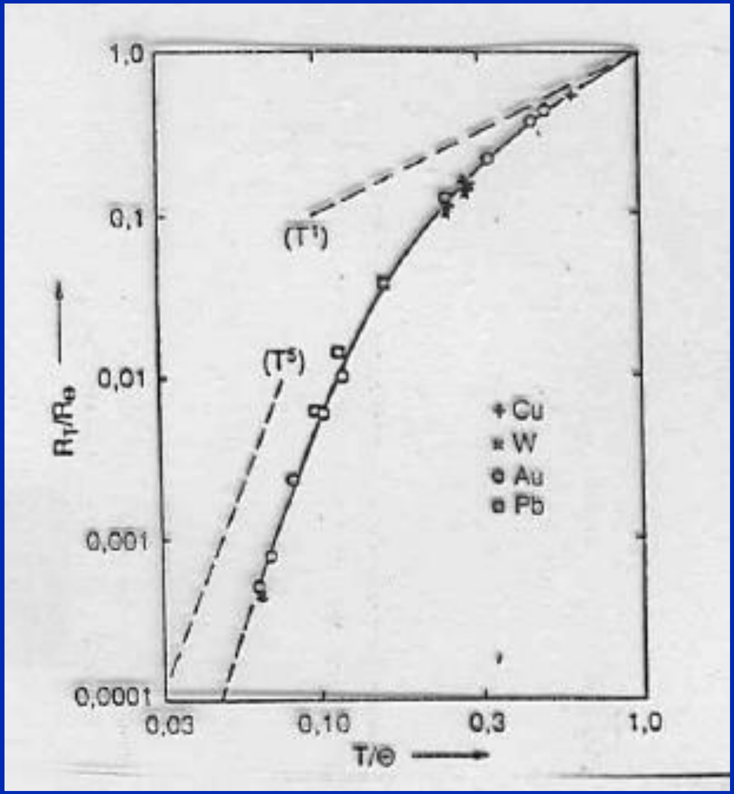
(4) Very high temperatures

saturation as the phonon scattering cannot lead to mean free path-lengths shorter than the lattice constant (Ioffe rule)

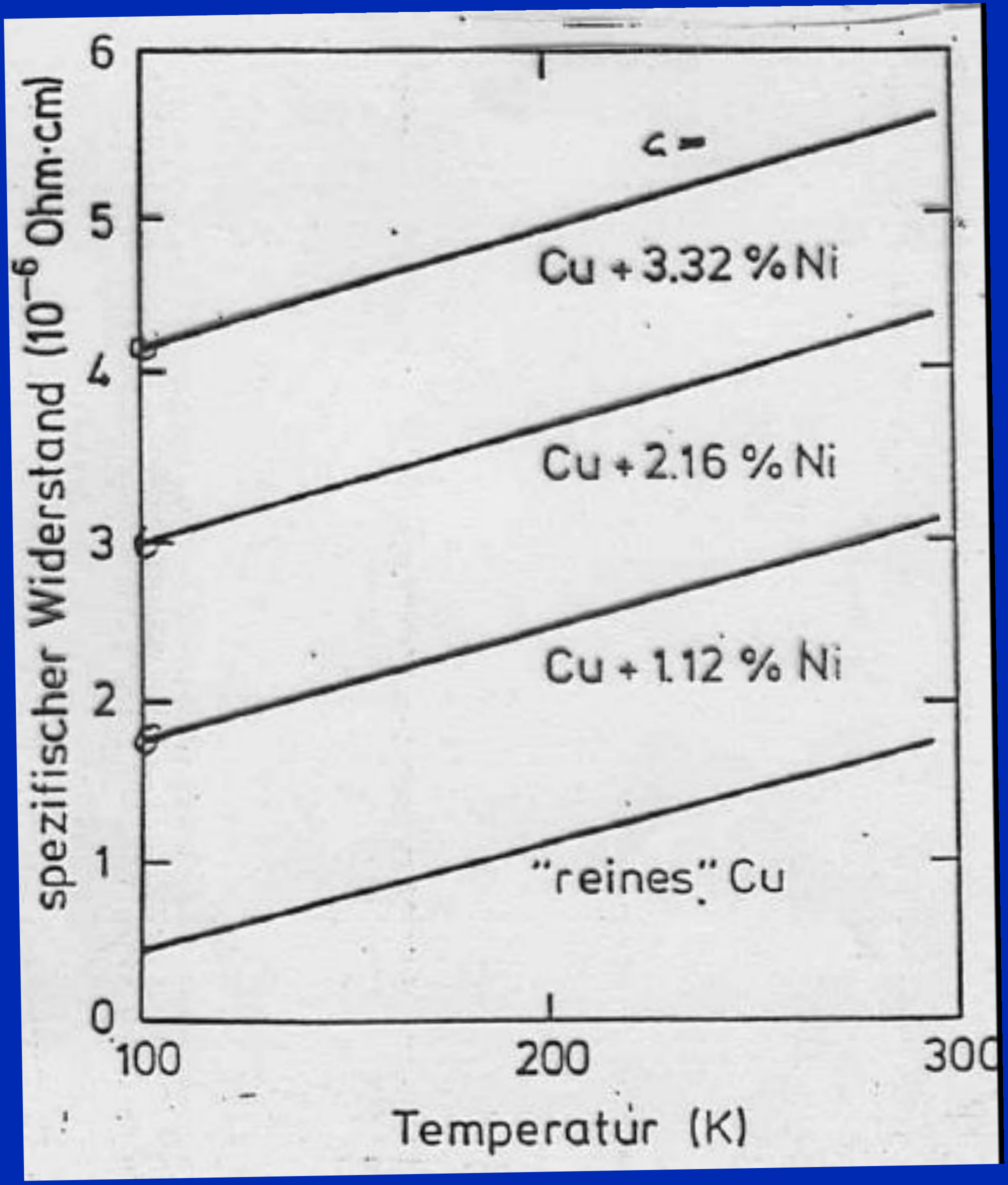
The resistance roughly scales with the Debye temperature !



Transition from T^5 to T behavior !



Matthiessen rule: alloys→ vertical displacement of ρ(T) curves



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Quantized Conductance of Point Contacts in a Two-Dimensional Electron Gas

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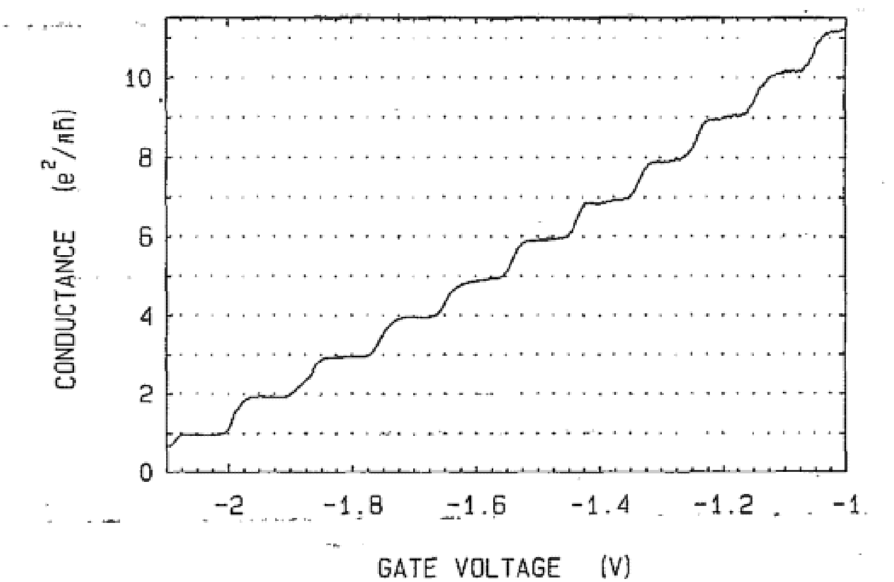

FIG. 2. Point-contact conductance as a function of gate voltage, obtained from the data of Fig. 1 after subtraction of the lead resistance. The conductance shows plateaus at multiples of $e^2/\pi\hbar$.