SUMMARY - ELECTRONIC SPECIFIC HEAT

$C_V = \gamma \cdot T$

γ = SOMMERFELD CONSTANT

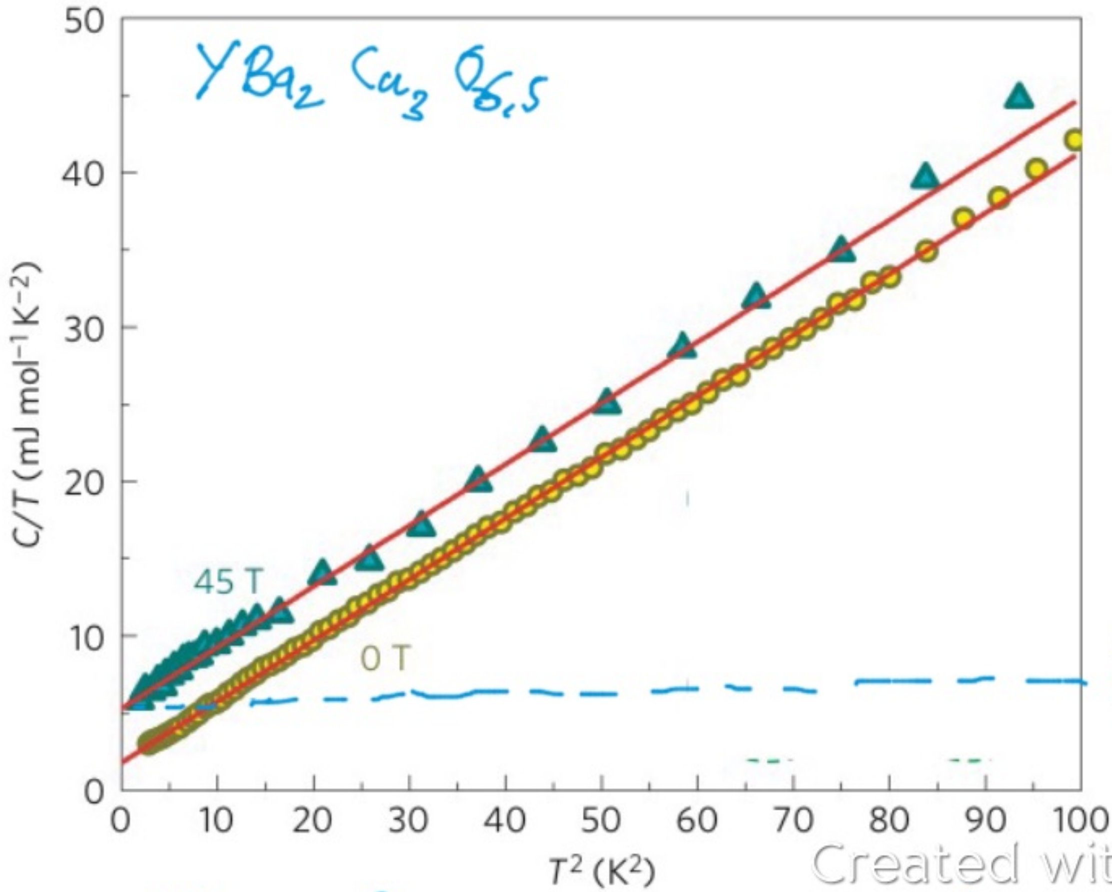
$$\left.\begin{aligned} \gamma &= \frac{\pi^2}{3} D(\varepsilon_F) k_B^2 \\ &= \frac{\pi^2}{2} N \cdot k_B \frac{1}{T_F} \end{aligned}\right\}$$

DIFFERENT FORMULATIONS OF THE SAME RESULT

EXERCISE: Show that $\gamma \propto m$ where m = electron mass

ELECTRONIC MASS

$$\frac{\gamma(\text{OBSERVED})}{\gamma_{free}} = \frac{m_{OBSERVED}}{m_{free}}$$



γ(OBSERVED)

$\frac{5\,\text{mJ}}{\text{mol K}^2}$

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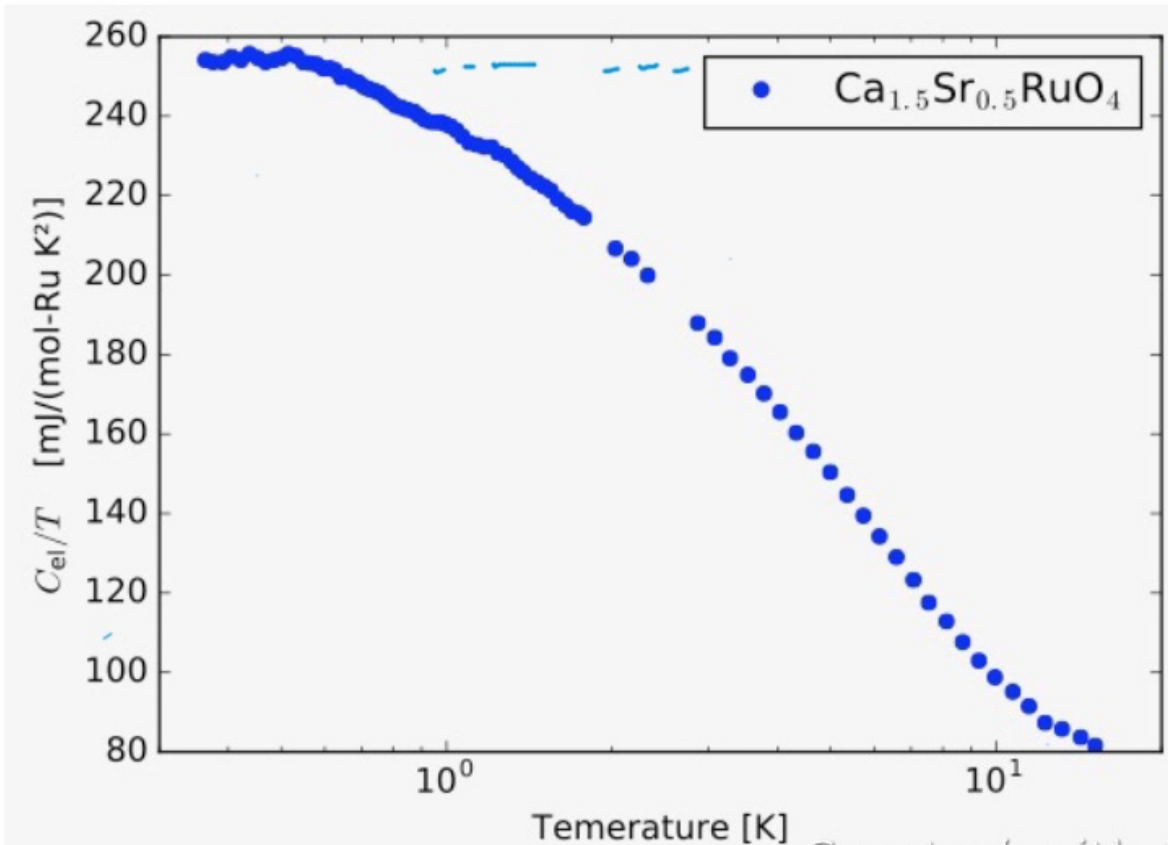
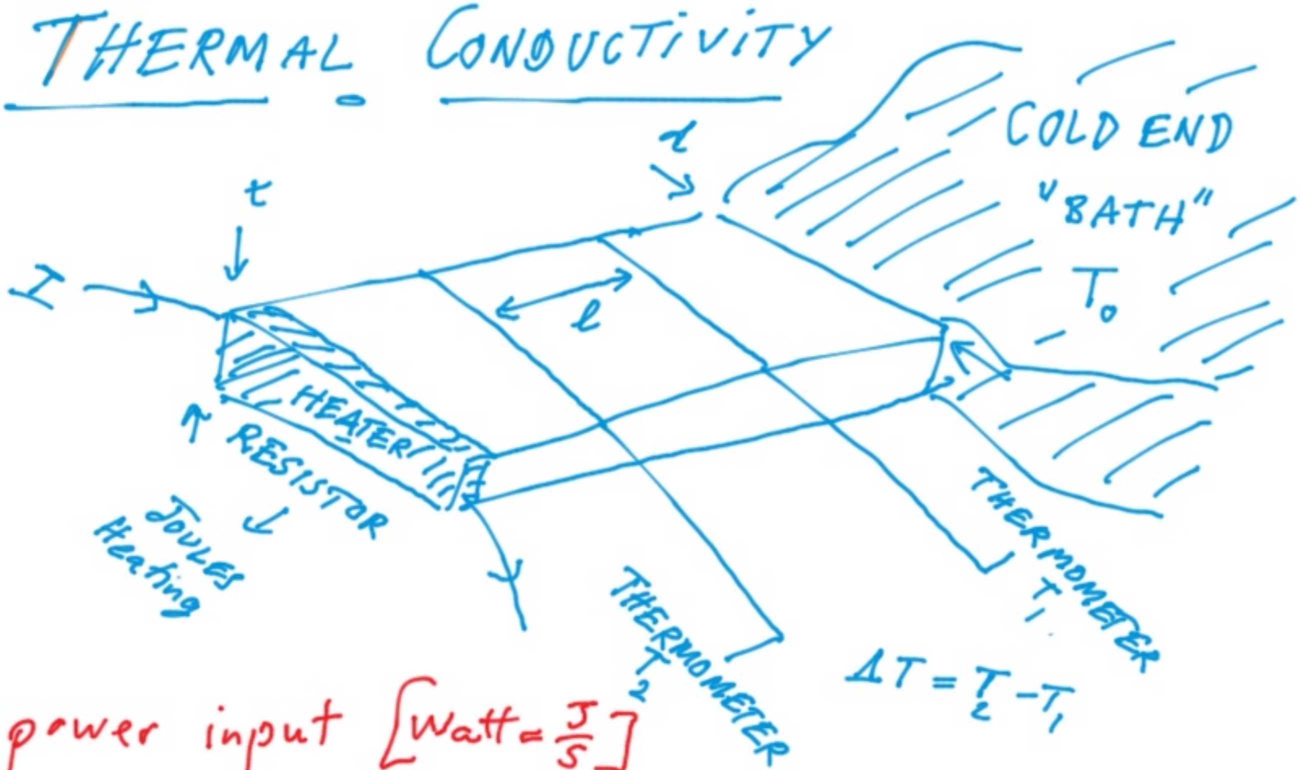
HEAVY-FERMIONS:



γ (OBSERVED)

$250 \frac{mJ}{mol\, K^2}$

THERMAL CONDUCTIVITY.



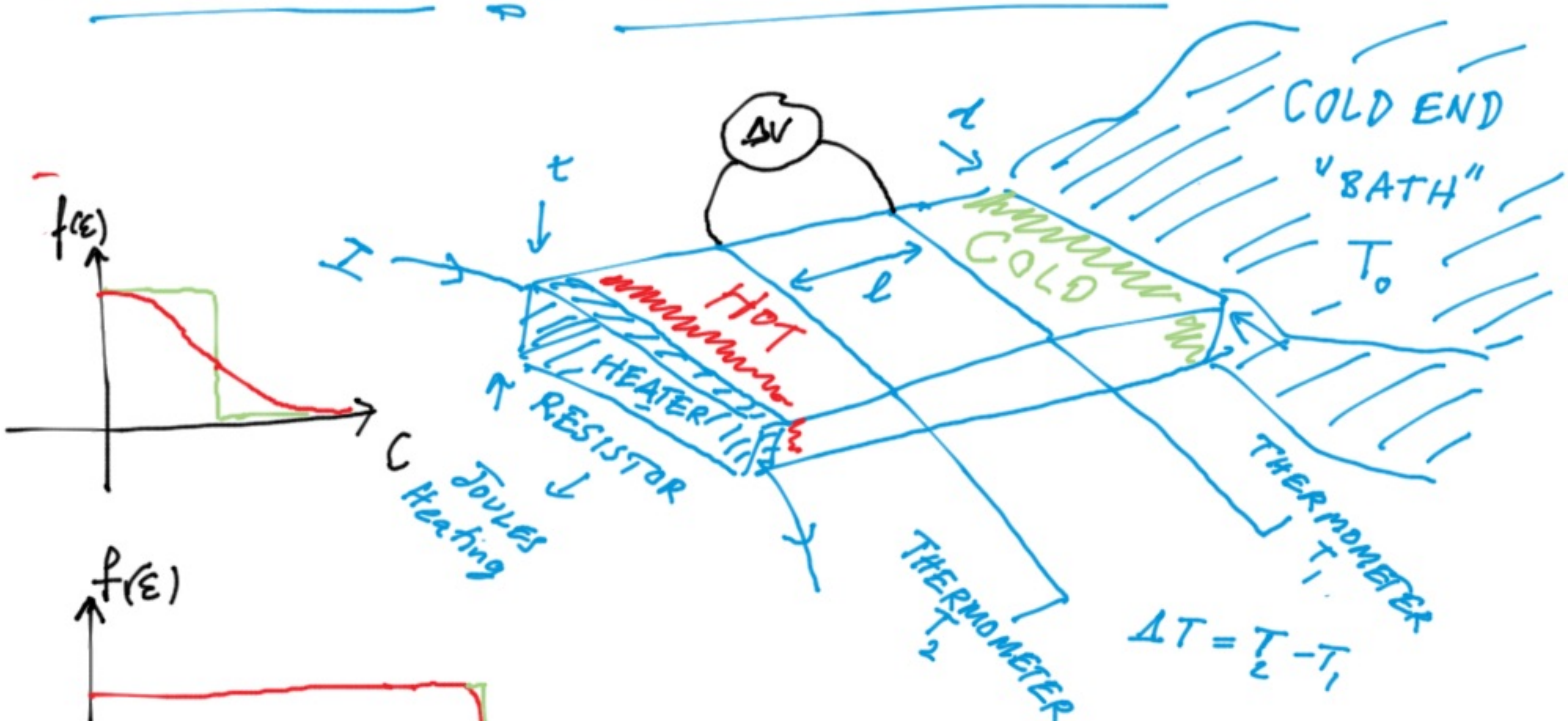
P = power input $\left[\text{Watt} = \frac{J}{s}\right]$

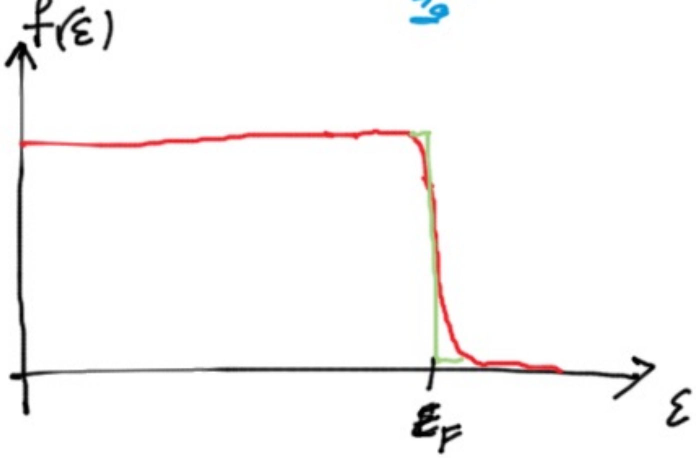
A = cross section $= t \cdot d$

k = thermal conductivity $\equiv \dfrac{P/A}{\Delta T/\ell} = \dfrac{\ell}{A} \cdot \dfrac{P}{\Delta T}$

$k_{el} \propto C \propto T$

THERMOPOWER / SEEBECK EFFECT

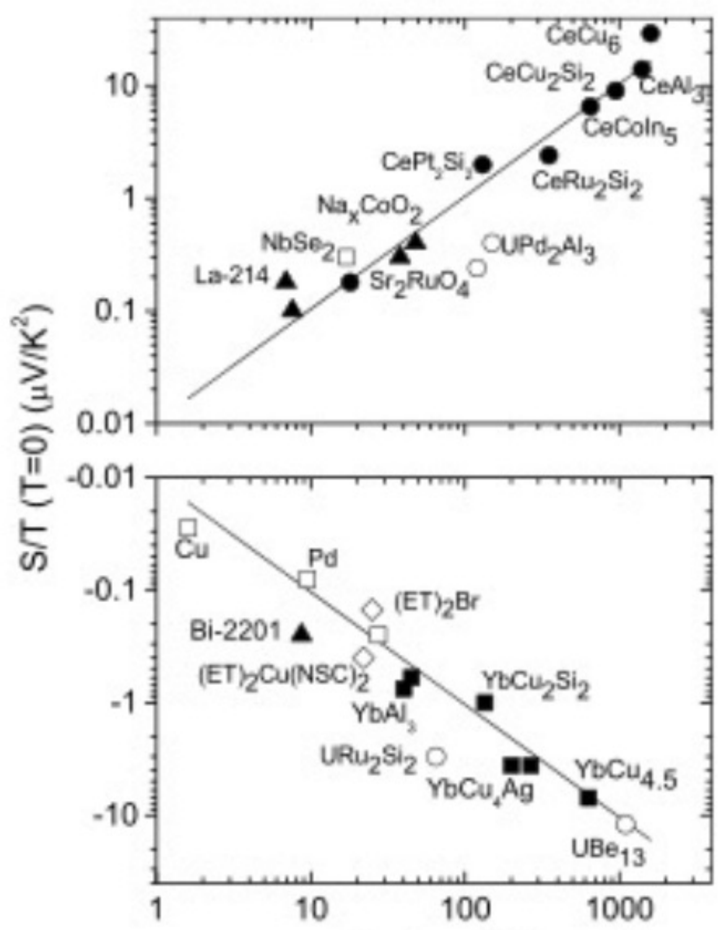




$$S \equiv \frac{\Delta V}{\ell} \Big/ \frac{\Delta T}{\ell} = \frac{\Delta V}{\Delta T}$$

$$S = -\frac{\pi^2}{2}\frac{k_B}{e}\frac{T}{T_F}$$

COMPARE: SPECIFIC HEAT & THERMOPOWER

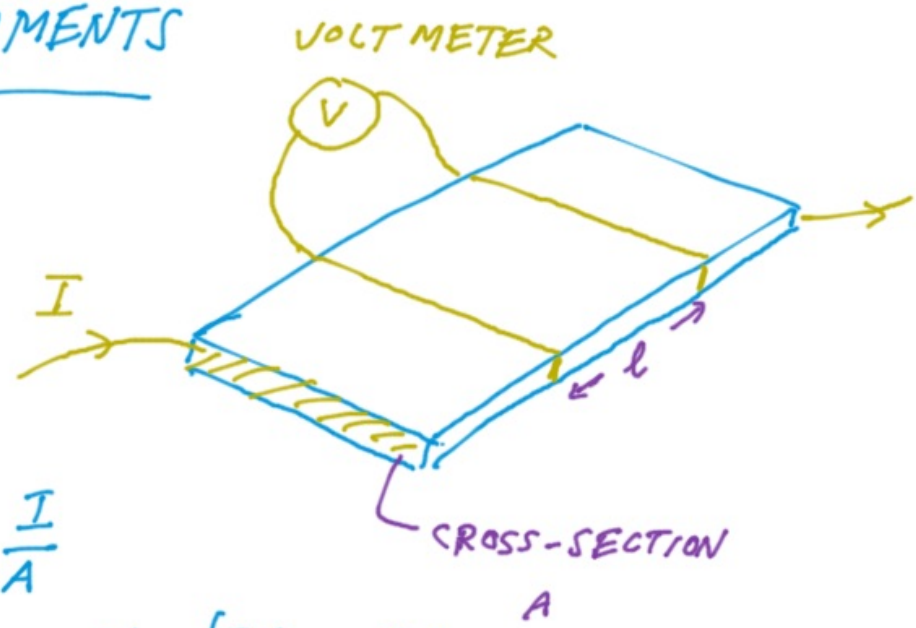


$= \frac{C_V}{T}$

$$S = \pm\frac{\pi^2}{2}\frac{k_B}{e}\frac{T}{T_F}$$

$$C_V = \frac{\pi^2}{2} N \cdot k_B \frac{T}{T_F}$$

Resistivity Experiments



Ohm's Law: $V = R \cdot I$

R = RESISTANCE

CURRENT DENSITY: $j = \dfrac{I}{A}$

VOLTAGE BETWEEN 2 POINTS: $V = \int E\,dx = E \cdot l$

ELECTRICAL FIELD

Ohm's Law Reformulated:

$$E l = R \cdot A j \Rightarrow E = \frac{A}{l} \cdot R j = \rho \cdot j$$

or

$$j = \sigma E$$

where $\rho = \frac{A}{l} R$ = resistivity

$\sigma = 1/\rho$ = conductivity

DRUDE CONDUCTIVITY

$$m\frac{dv}{dt} + \frac{mv}{\tau} = F = -eE$$

$$E \propto e^{i\omega t}$$

$$V \propto e^{i\omega t}$$

$$\left(i\omega + \frac{1}{\tau}\right)mv = -eE \Rightarrow V = \frac{-eE}{\left(i\omega + \frac{1}{\tau}\right)m} \overset{\substack{DC \\ \omega \to 0}}{=} \frac{-eE\tau}{m}$$

$$j = -nev = \frac{ne^2\tau}{m} \cdot E$$

$$\left.\begin{aligned} \sigma &= \frac{ne^2\tau}{m} = ne\mu \\ \rho &= \frac{m}{ne^2\tau} = \frac{1}{ne\mu} \end{aligned}\right\} \text{ where } \mu = \frac{e\tau}{m} = \text{electron mobility}$$

LANDAU FERMI LIQUID: electron-electron scattering

Related to impurity scattering

$$\rho = \rho_0 + A \cdot T^2$$

ρ_0 = Residual resistivity

RESIDUAL-RESISTIVITY RATIO

$$RRR = \frac{\rho(300K)}{\rho(0K)}$$

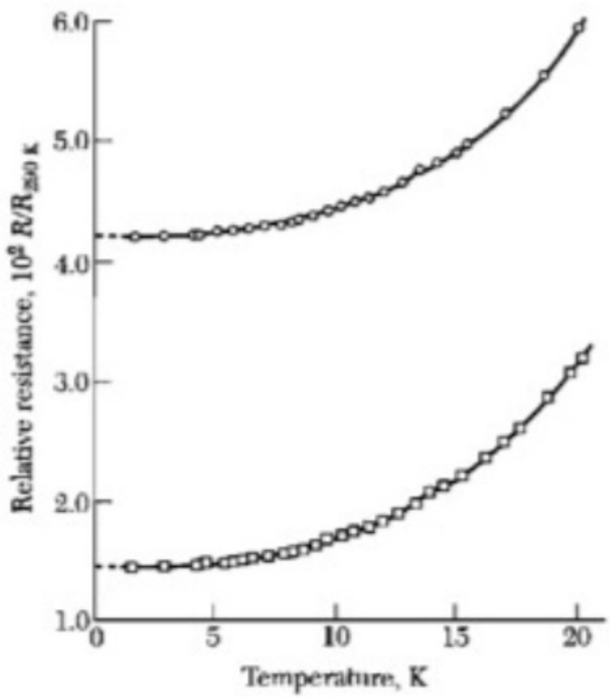
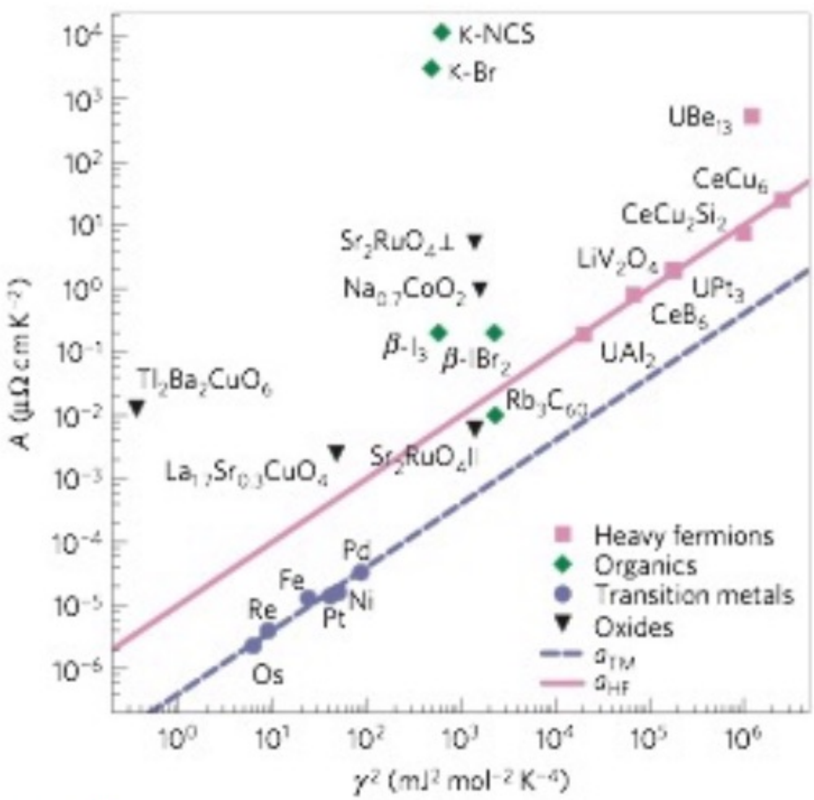


Figure 12 Resistance of potassium below 20 K, as measured on two specimens by D. MacDonald and K. Mendelssohn. The different intercepts at 0 K are attributed to different concentrations of impurities and static imperfections in the two specimens.

KADOWAKI - Woods Relation : HUMAN RATIONALIZATION



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WIEDERMANN – FRANZ RELATION:

$$\sigma = \frac{n e^2 \tau}{m}$$

$$\kappa_{el} = \frac{1}{3} C \cdot v \cdot \ell = \frac{\pi^2 n k_B^2 T \tau}{3m}$$ (See KITTEL)

$$\Downarrow \quad \frac{\kappa_{el}}{\sigma} = \frac{\pi^2}{3} \left(\frac{k_B}{e} \right)^2 \cdot T$$

NOT TO FORGET

($T \to 0\,K$ limit)

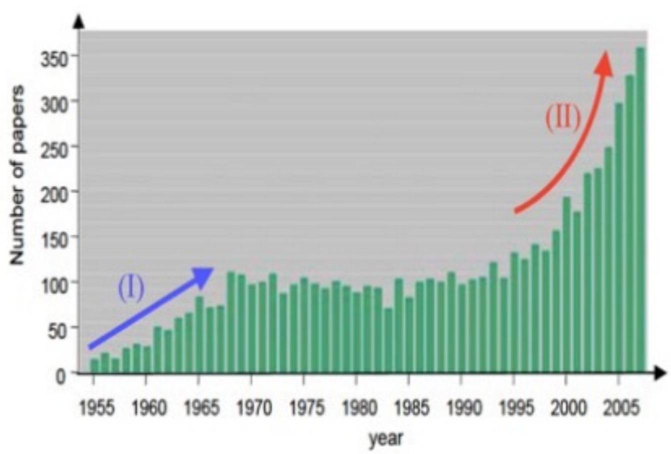
LORENZ NUMBER

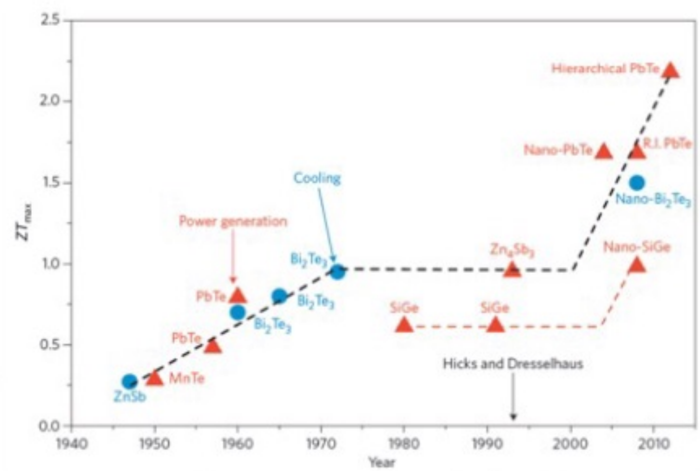
$$L \equiv \frac{\kappa_{el}}{\sigma \cdot T} = \frac{\pi^2}{3} \left(\frac{k_B}{e} \right)^2 = 2.45 \cdot 10^{-8} \text{ Watt-}\Omega/K^2$$

THERMO-ELECTRICITY: FIGUR-OF-MERIT

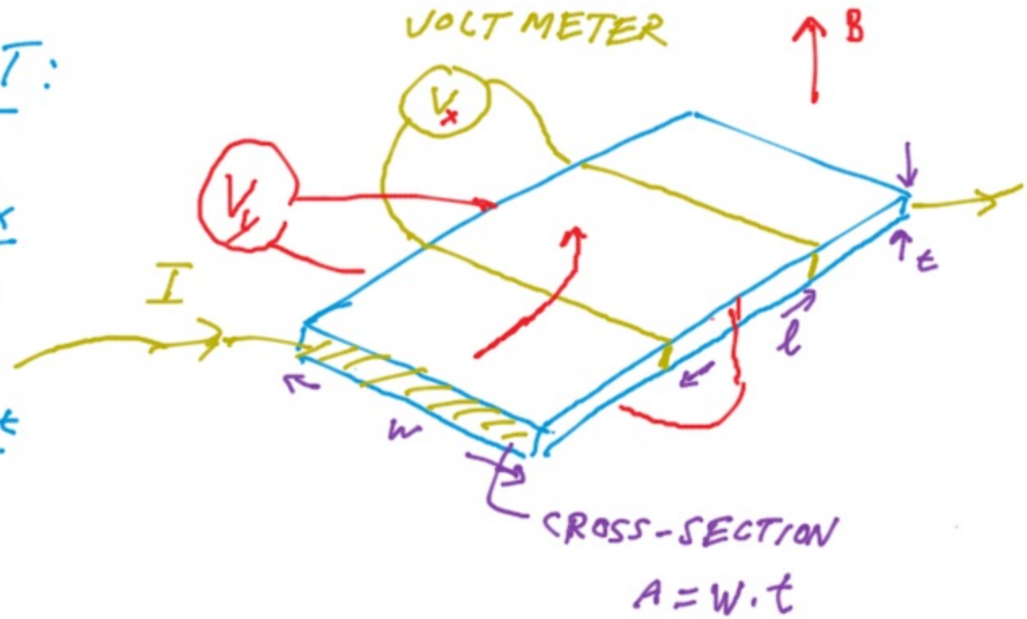
$$zT = \frac{\sigma S^2 \cdot T}{\kappa} \qquad \text{(HUMAN CONSTRUCTION)}$$

$$\kappa = \kappa_{phonons} + \kappa_{electrons}$$





HALL EFFECT:



$$R_{xx} = \frac{V_x}{I_x} \; ; \; \rho_{xx} = \frac{E_x}{j_x}$$

$$\rho_{xy} = \frac{E_y}{j_x} = \frac{V_y/w}{I_x/wt} = \frac{V_y \cdot t}{I_x}$$

$$R_{xy} = \frac{V_y}{I_x} = \rho_{xy} \cdot \frac{1}{t}$$

(0) $F = -e\left(\vec{E} + \vec{v}_x \vec{B}\right)$ FORCE

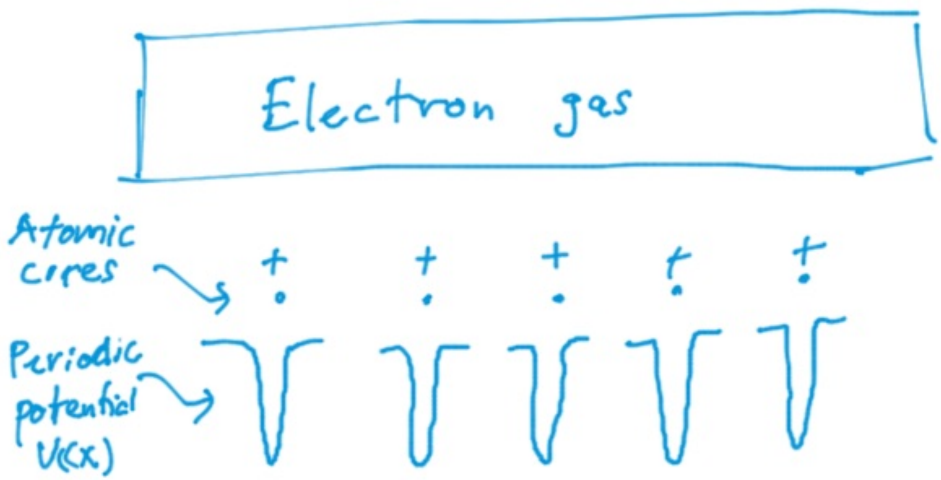
(1) $E_y = v_x \cdot B_z$

(2) $j_x = -e n v_x$

(3) $V_y = E_y \cdot W = v_x \cdot B_z \cdot W = \frac{-j_x}{ne} B_z \cdot W = \frac{-I_x}{W \cdot t} \cdot \frac{B_z}{en} \cdot W = \frac{-I_x}{t} \frac{B_z}{en}$

$\rho_{xy} = -\frac{B}{en} \Rightarrow R_H \equiv \frac{\rho_{xy}}{B} = \frac{-1}{en} =$ HALL COEFFICIENT

BAND STRUCTURE – BACKGROUND:



Schrödinger Equation

$$\left\{\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2} + V(x)\right\}\psi(x) = E\,\psi(x)$$

What happens to $\psi(x)$ and E when $V(x) \neq 0$.