Peltier, Seebeck and Thompson Effects

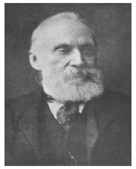
(V)

(1934)

Peltier: $$\pi_{ab} = \pi_a - \pi_b = \frac{Q}{I}$$

Thomson relation: $$\begin{cases} \pi = S \cdot T \\ \mu = \frac{dS}{dT} T \end{cases}$$

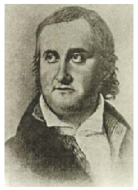
(VK^{-1})



(1954)

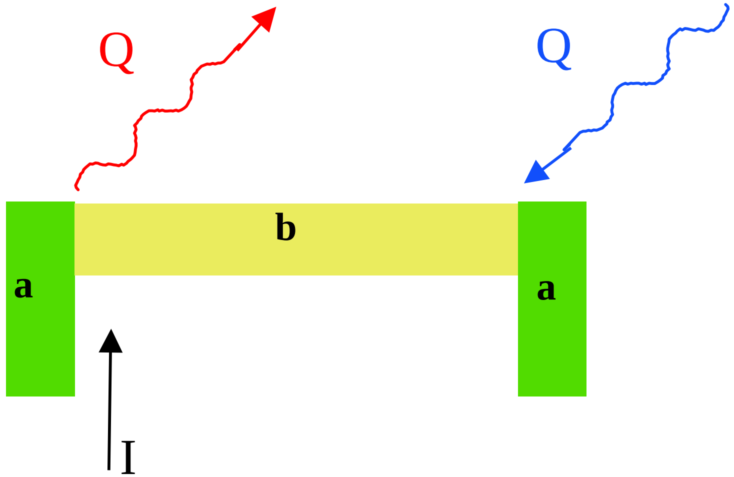
Thomson

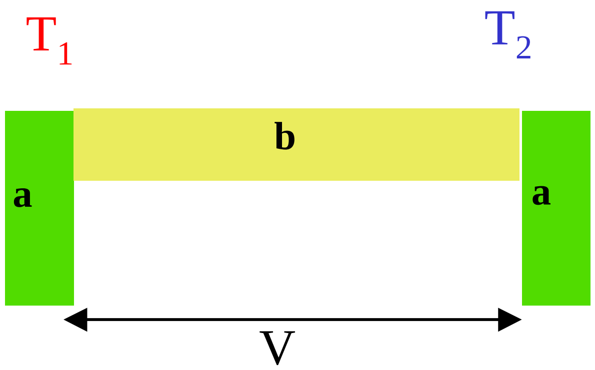
(VK^{-1})



(1921)

Seebeck: $$S = \frac{\Delta V}{\Delta T}$$





material a

material b

Thermoelectric power conversion-basic data

$$ZT = \frac{\alpha^2}{\rho\lambda} T$$

Seebeck Coefficient

Temperature

Thermal Conductivity

El. resistivity

Figure of merit

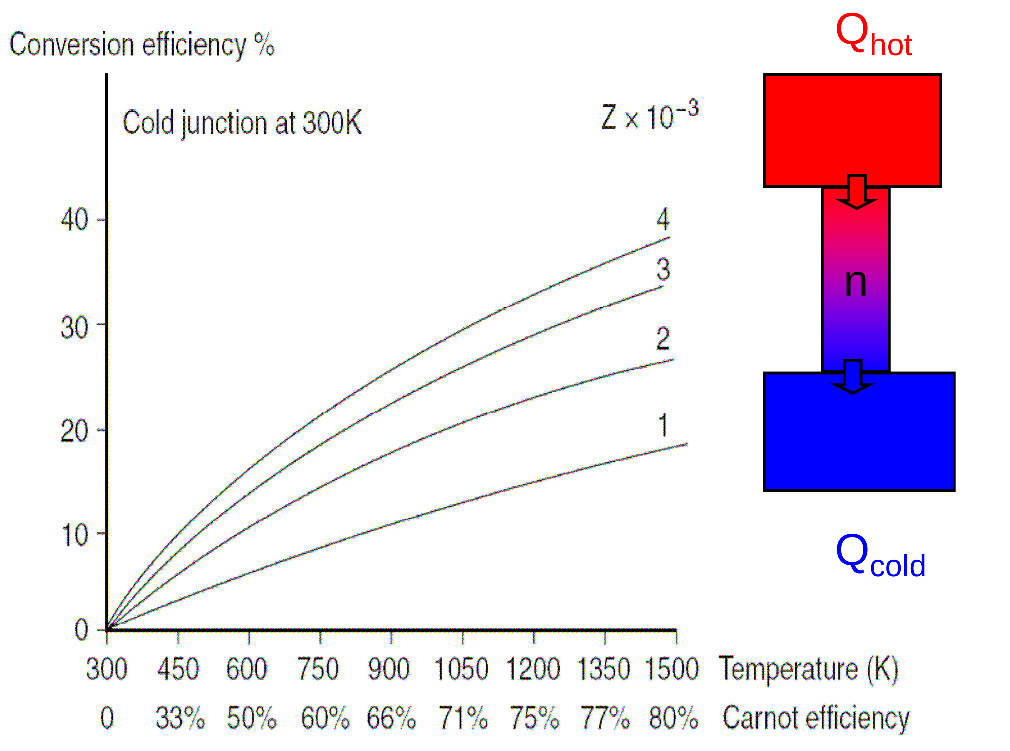
ZT Determines Efficiency

Carnot efficiency

Thermoelectric efficiency

Electricity Generation

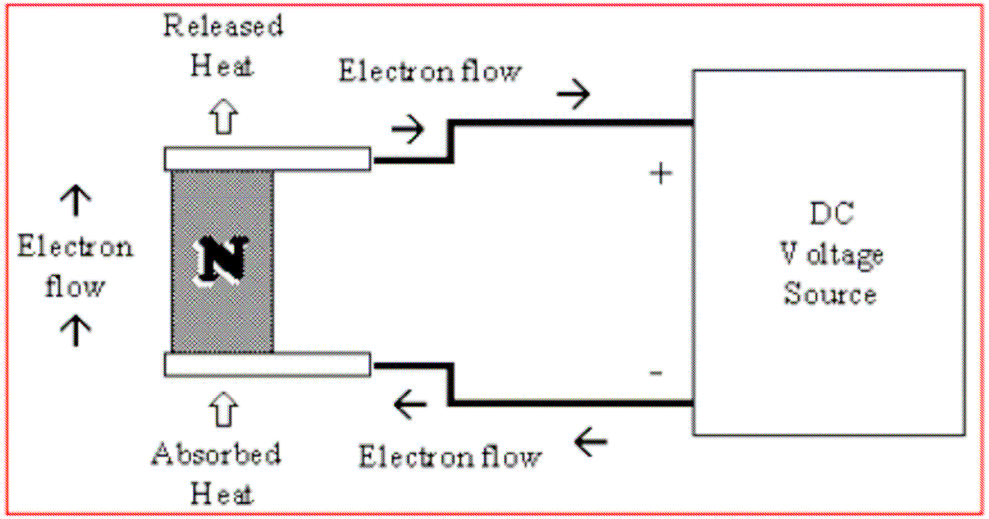
$$\eta = \frac{T_H - T_C}{T_H} \frac{\sqrt{1+ZT} - 1}{\sqrt{1+ZT} + \frac{T_C}{T_H}}$$



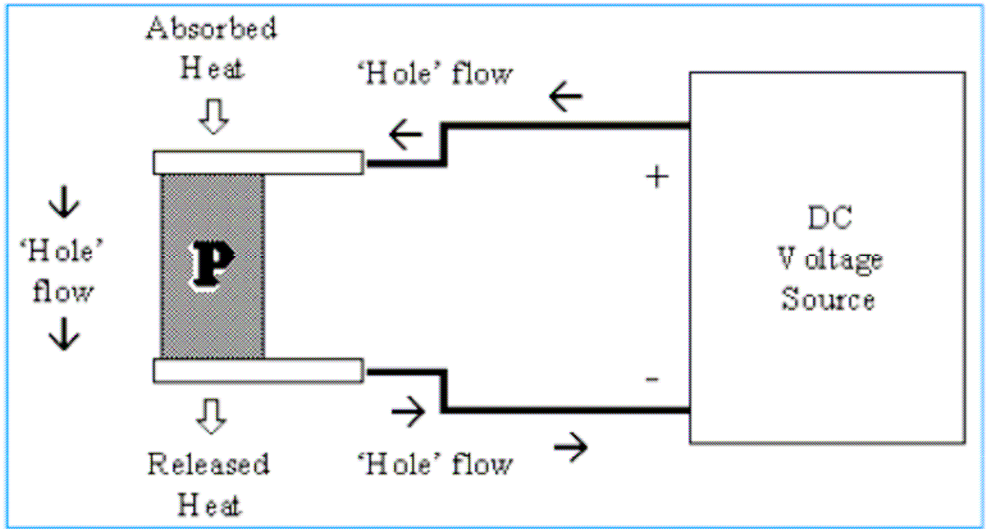
Temperature Cooling

$$(C.O.P.)_{max} = \frac{T_C}{T_H - T_C} \frac{\sqrt{1+ZT} - \frac{T_H}{T_C}}{\sqrt{1+ZT} + 1}$$

Thermoelectric cooler -basic data



n- type semiconductor



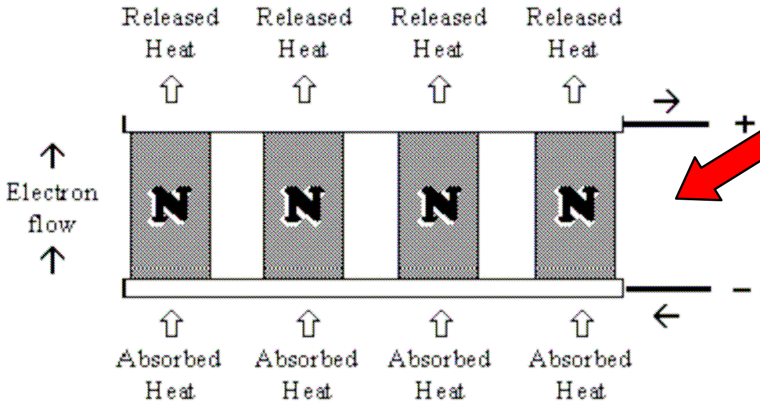
p- type semiconductor

Thermoelectric converter battery -basic data

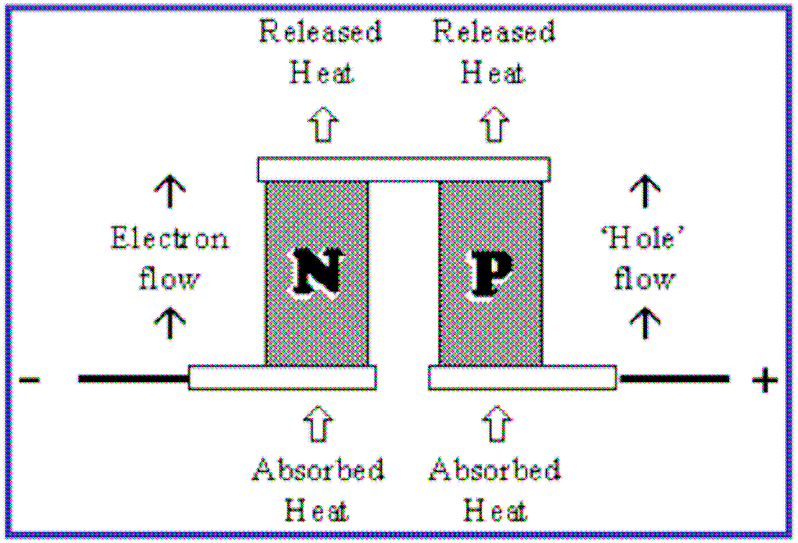
One type of material

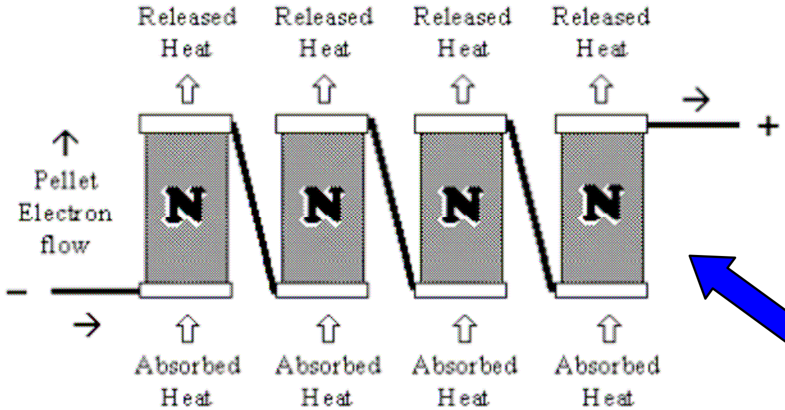
P-N couple

Thermally, electrically parallel



High current – low voltage



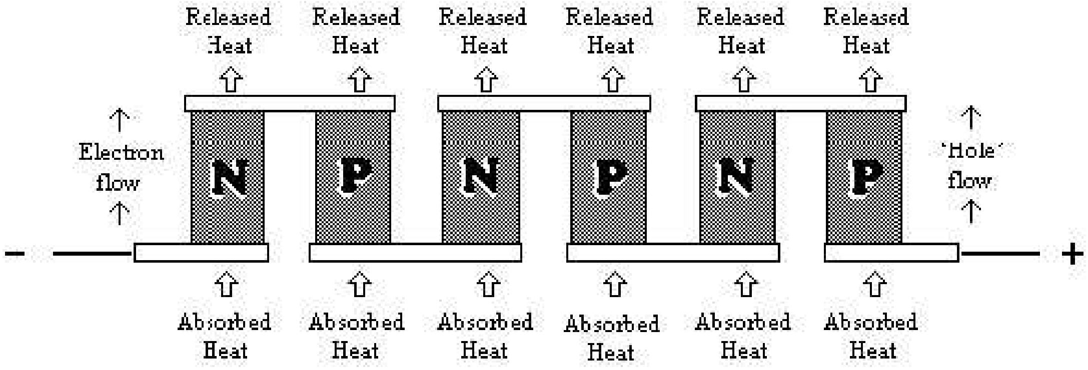


Contact heating

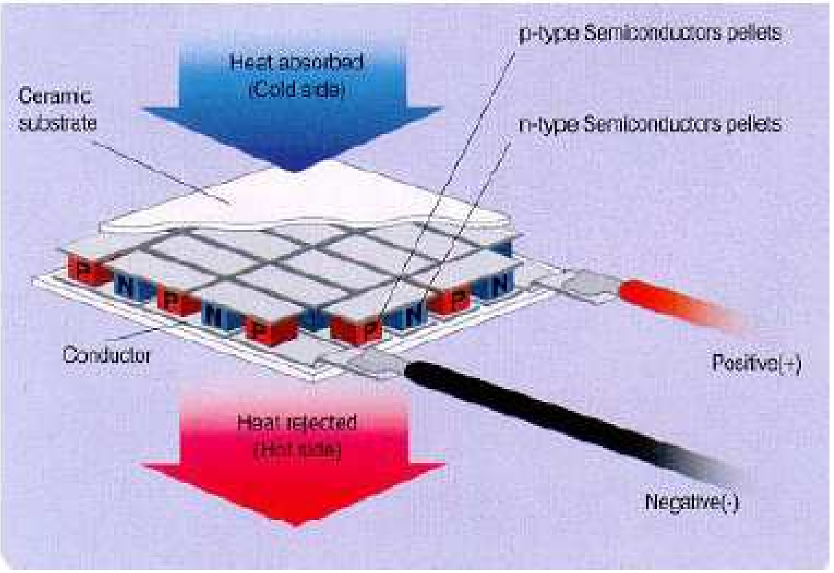
Thermal shortcut

Thermally parallel, electrically in series

Thermoelectric convertor -basic data



Multi-couple configuration increases heat-pumping capacity

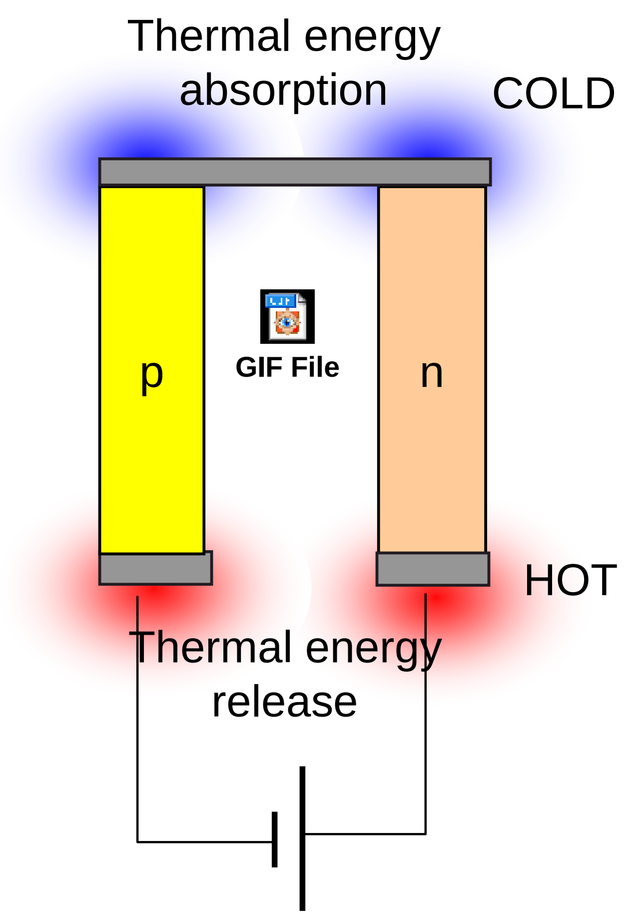


High voltage - low current

Thermoelectric couple- key element of the thermal to electrical energy conversion

PELTIER (1834)

COOLING

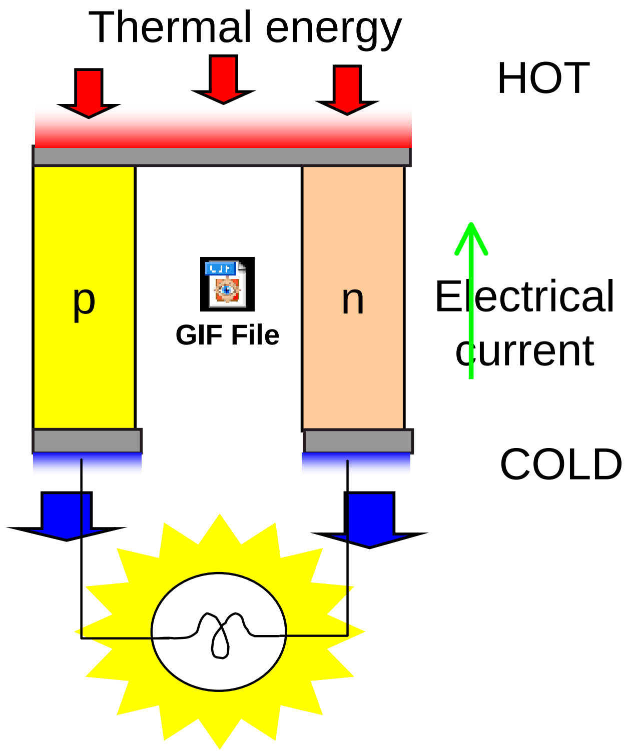


<u>Thermoelectricity</u>

direct conversion of heat into electricity
&
vice versa
Uses semiconductors, semimetals, thermoelectric alloys, ceramics, oxides,...

SEEBECK (1821)

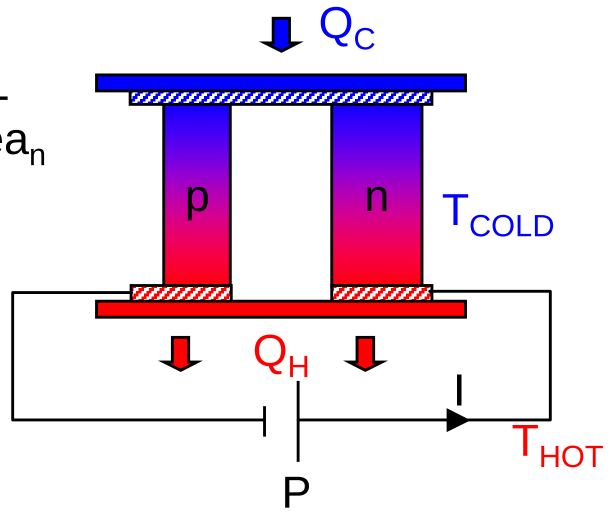
Electricity generation



Mathematical description of thermoelectric unicouple ideal energy ballance

Cooling

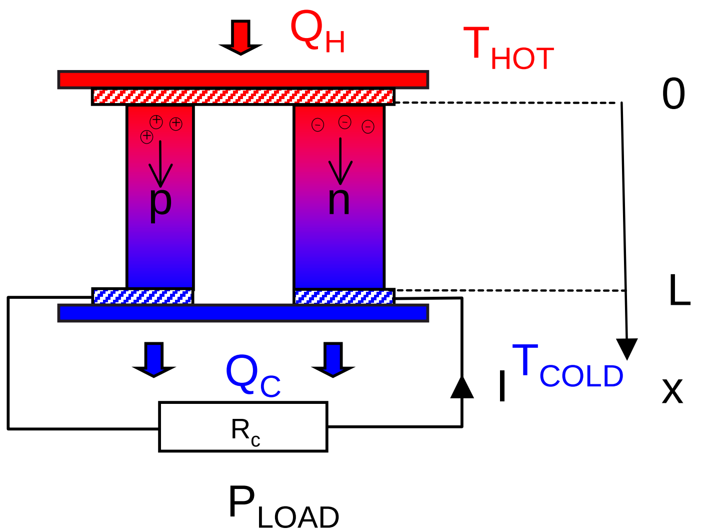
$L_p = L_n = L$
$Area_p, Area_n$
α_p, α_n
λ_p, λ_n
ρ_p, ρ_n



$$P = Q_C + Q_H$$

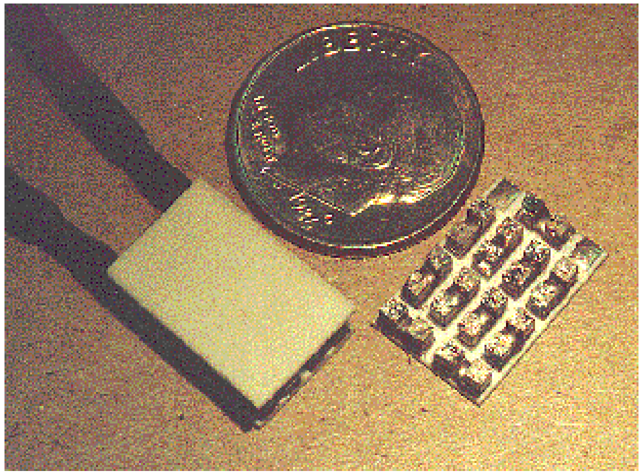
$$C.O.P. = \frac{Q_H}{P}$$

Energy Generation



$$Q_H = P_{LOAD} + Q_C$$

$$\eta = \frac{P_{LOAD}}{Q_H}$$

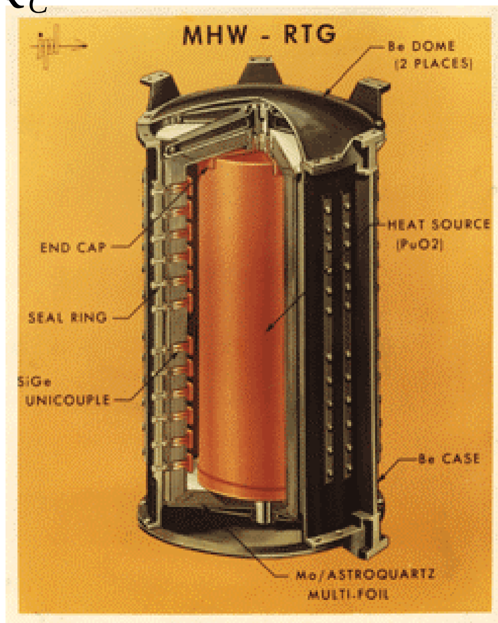


Commercial Thermoelectric Modules

ΔT=72C

- Cooling density <10W/cm²
- Efficiency 6-8% of Carnot

Thermoelectric modules are used by NASA to power satellites in space



Mathematical description of thermoelectric unicouple ideal energy ballance

Cooling

$$C.O.P. = \frac{Q_C}{P} = \frac{-\alpha T_C I - K\Delta T - \frac{1}{2}RI^2}{RI^2 - \alpha \Delta T I}$$

Maximum C.O.P. $\left(\frac{\partial C.O.P.}{\partial I}\right) = 0$

$$(C.O.P.)_{\max} = \underbrace{\frac{T_C}{T_H - T_C}}_{\text{Carnot}} \frac{\sqrt{1+ZT} - \frac{T_H}{T_C}}{\sqrt{1+ZT} + 1}$$

Generator

$$\eta = \frac{P_{LOAD}}{Q_H} = \frac{R_{LOAD} I^2}{K\Delta T - \alpha T_H I - \frac{1}{2}RI^2}$$

Maximum η : $\left(\frac{\partial \eta}{\partial R_c}\right) = 0$

$$\eta_{\max} = \underbrace{\frac{T_H - T_C}{T_H}}_{\text{Carnot}} \frac{\sqrt{1+ZT} - 1}{\sqrt{1+ZT} + \frac{T_H}{T_C}}$$

T : average temperature

$$Z = \frac{\alpha^2}{\rho\lambda} = \frac{P_f}{\lambda}$$

Z , $P_{f,}$ s: figure of merit, power factor, compatibility factor

When different materials or large ΔT are used
(which is actually a general case) the **thermoelectric compatibility** in
T and material must also be considered

$$s = \frac{\sqrt{1+ZT} - 1}{\alpha T}$$

Applications of P-N couple – ideal matching of properties

Mathematical description of thermoelectric unicouple efficiency

Cooling

$$C.O.P. = \frac{Q_f}{P} = \frac{\alpha_{pn} T_C I - K\Delta T - \frac{1}{2} R I^2}{R I^2 - \alpha \Delta T I}$$

Electricity Generation

$$\eta = \frac{P_{LOAD}}{Q_H} = \frac{R_c I^2}{K\Delta T + \alpha_{pn} T_H I - \frac{1}{2} R I^2}$$

$$\frac{Area_p}{Area_n} = \sqrt{\frac{\rho_p \lambda_n}{\rho_n \lambda_p}}$$

$$(C.O.P.)_{\max} = \frac{T_C}{T_H - T_C} \frac{\sqrt{1 + Z_{np} T} - \frac{T_H}{T_C}}{\sqrt{1 + Z_{np} T} + 1}$$

Carnot

$$(\eta)_{\max} = \frac{T_H - T_C}{T_H} \frac{\sqrt{1 + Z_{np} T} - 1}{\sqrt{1 + Z_{np} T} + \frac{T_H}{T_C}}$$

Carnot

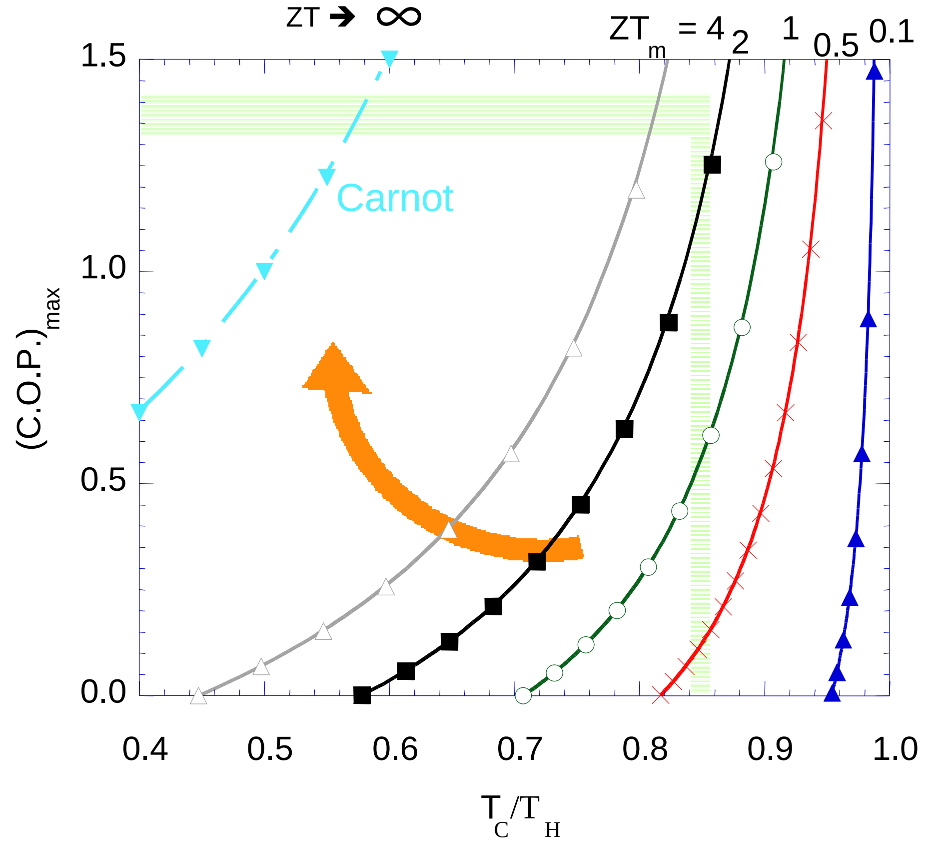
Factor of Merite of the P-N couple Z_{np}

$$Z_{np} = \frac{(\alpha_p - \alpha_n)^2}{[(\rho_p \lambda_p)^{1/2} + (\rho_n \lambda_n)^{1/2}]} \approx \frac{Z_n + Z_p}{2}$$

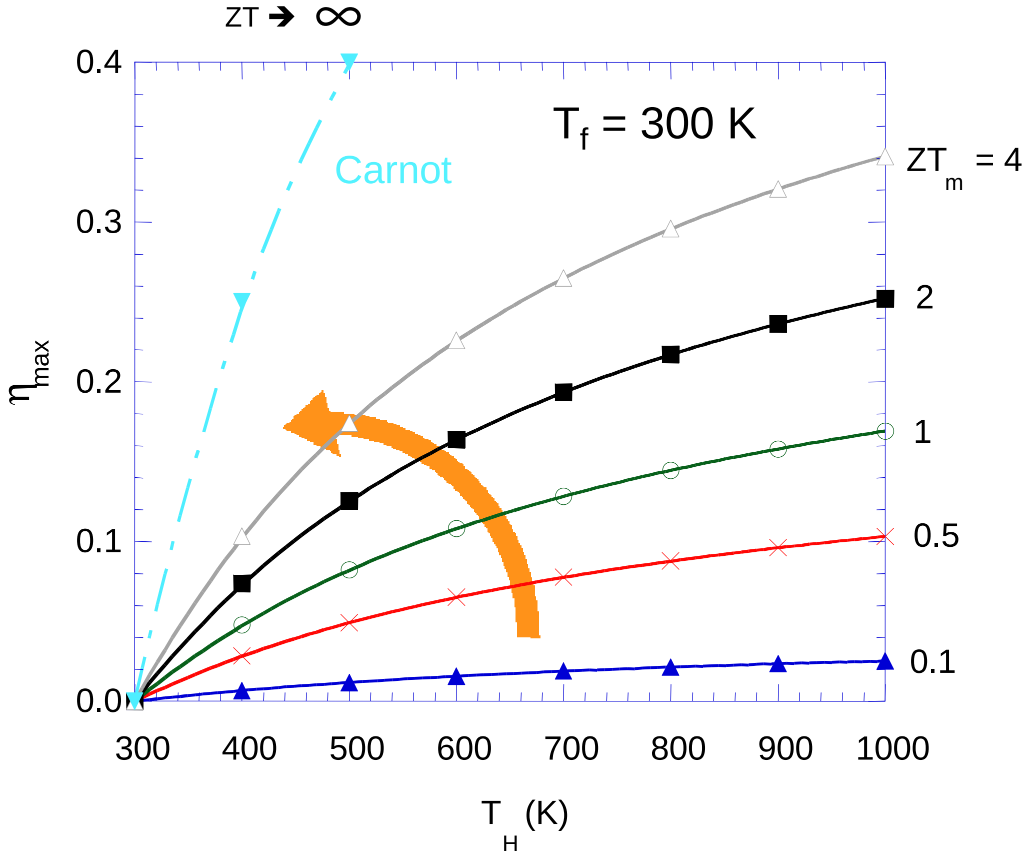
!! IF close properties !!

Graphical description of TE Performance

Cooling



Electricity Generation



High performance ➔ ZT high

Material criteria : ZT (factor of merit) high

Prerequisites for good thermoelectric materials

1. Semiconductor
2. Low carrier concentration
3. High Carrier Mobility
4. Low Thermal conductivity

1. Right band gap
2. Bad thermal conductor
3. Good electronic conductor
4. Scatter lattice vibration

MATERIAL