Lecture 4
Cryogenic Properties of Materials : Part II

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Thermal Conductivity of Non Metals

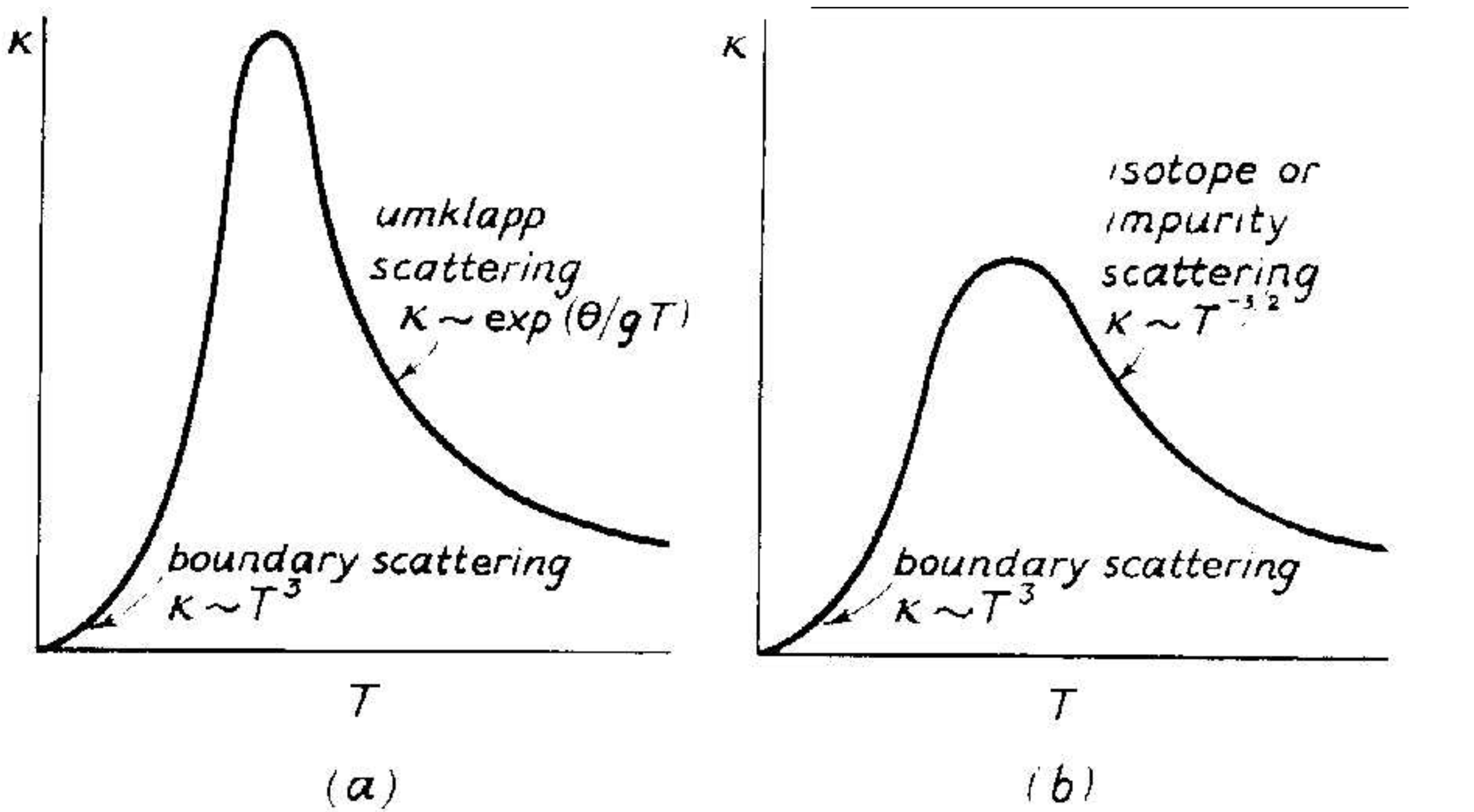
- Insulators: conduction heat transfer is completely caused by lattice vibrations (phonons)
- Semiconductors: conduction heat transfer is a mixture of phonon and electronic heat transfer

Scattering Mechanisms in Phonon Heat Transfer in Crystalline Materials

- Phonon/Phonon scattering (umklapp)
  - $W_u \sim AT^n \, \mathrm{Exp}(-\theta/gT)$
- Boundary scattering
  - $W_B \sim 1/T^3$ at very low temperatures
- Defect scattering
  - $W_D \sim AT^{3/2}$
- Dislocation scattering
  - $W_{dis} \sim A/T^2$

Schematic Thermal Conductivity in Dielectric Crystals

From Low Temperature Solid State Physics –Rosenburg



Thermal Conductivity of Amorphous Materials

- Mechanism is lattice vibrations
- Thermal conductivity is quite small (lack of regular structure)
- Thermal conductivity is proportional to specific heat and thus decreases with temperature

Thermal Conductivity Integrals

- The strong temperature dependence of K makes heat transfer calculations difficult
- The solution is frequently to use thermal conductivity integrals
- The heat conduction equation is written as:

$$Q = -G(\theta_2 - \theta_1)$$

Thermal Conductivity Integrals

- G is the geometry factor

$$G = \frac{1}{\int_{x_1}^{x_2} \frac{dx}{A(x)}}$$

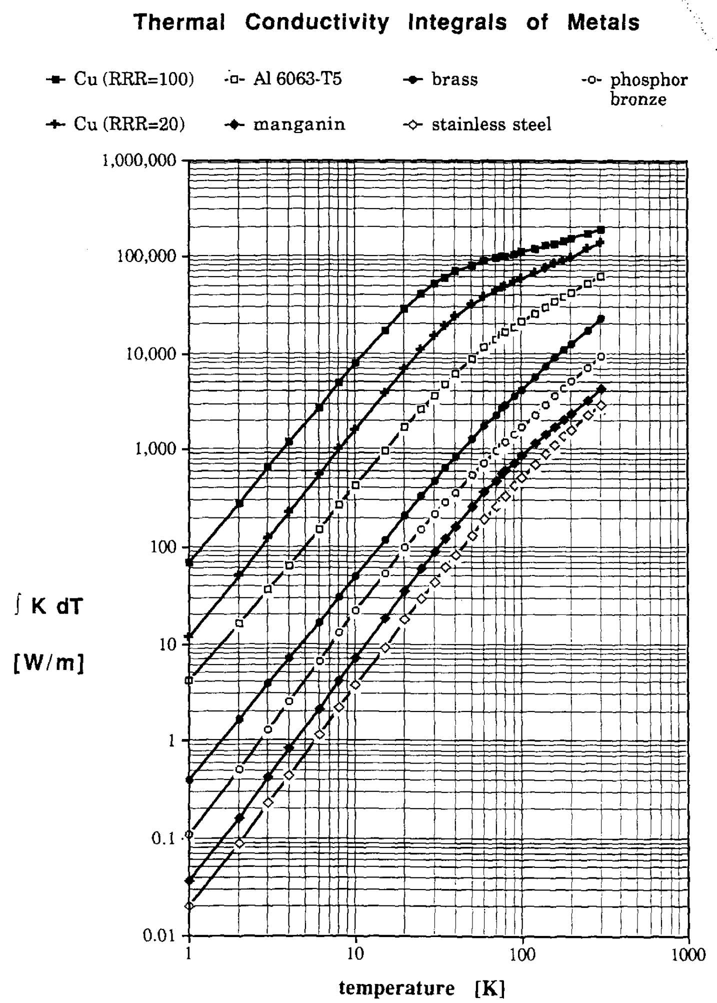
- θ is the thermal conductivity integral

$$\theta_i = \int_0^{T_i} K(T)\,dT$$

Thermal Conductivity Integrals

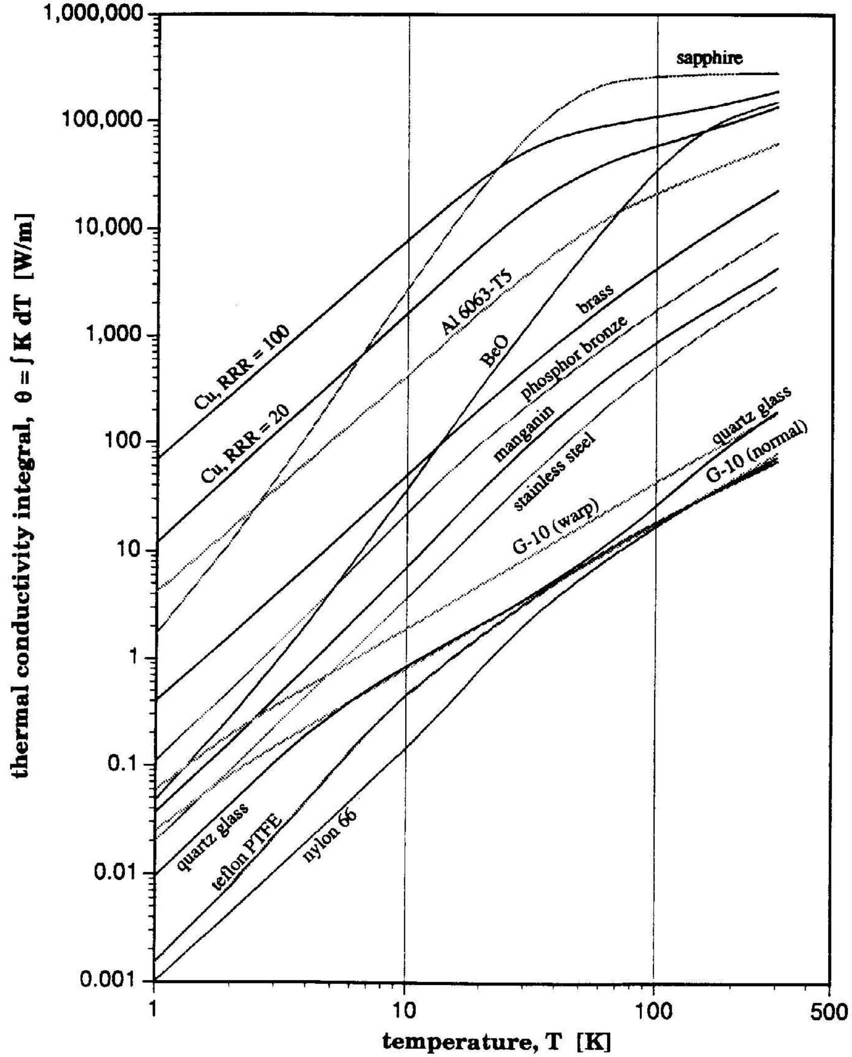
- Advantages:
  - Simple
  - Only end point temperatures are important. (assuming there are no intermediate heat sinks) The actual temperature distribution is not.
  - Thermal conductivity integrals have been calculated for many engineering materials
  - This is quite useful for heat leak calculations

Thermal Conductivity Integrals of Metals



From Handbook of Cryogenic Engineering, J. Weisend II (Ed)

Thermal Conductivity Integrals of Metals & Nonmetals



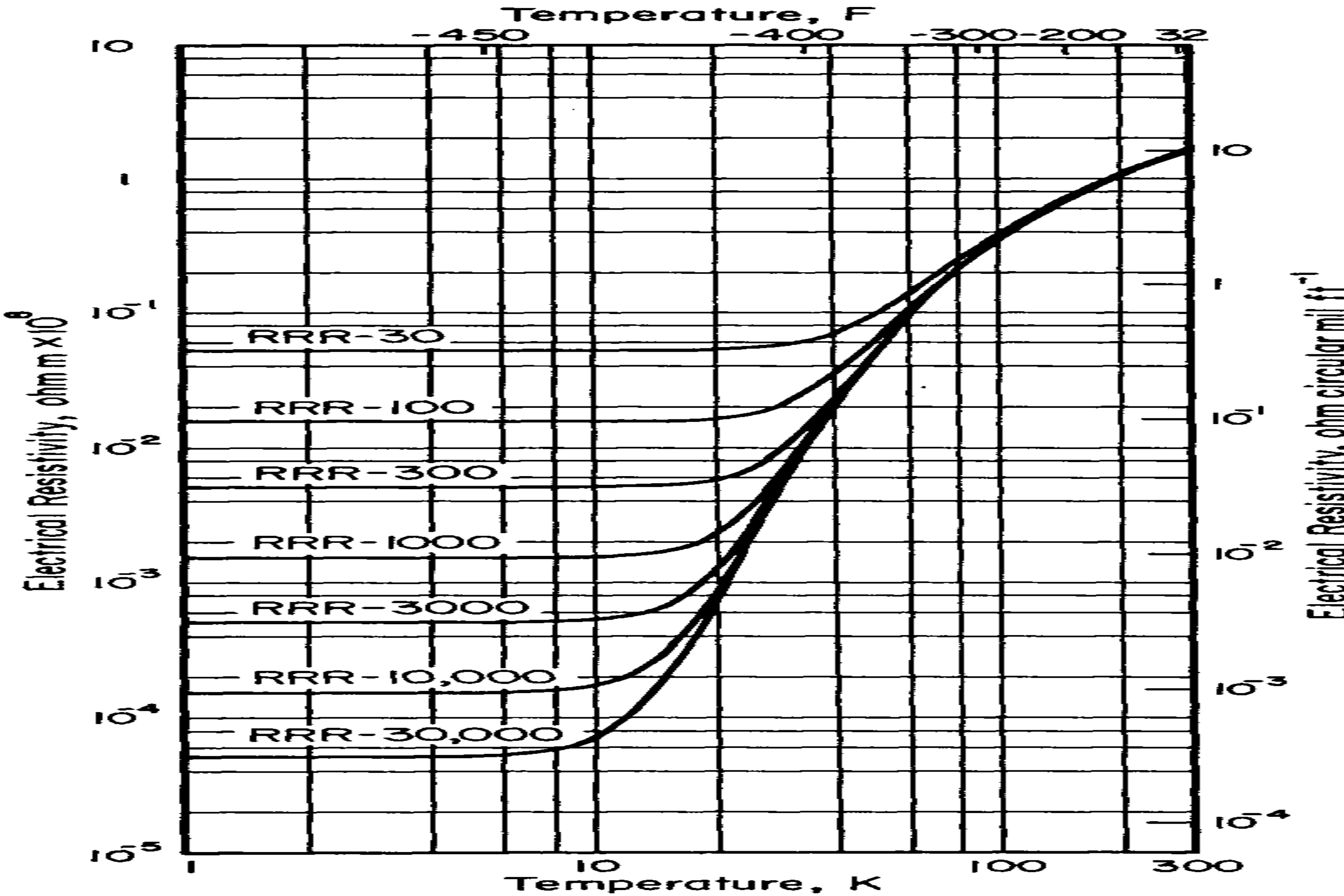
Electrical Resistivity

- Ohm's Law V=IR
  - R=ρL/A where ρ is the electrical resistivity
- Conduction electrons carry the current & there are 2 scattering mechanisms
  - Scattering of electrons off phonons
  - Scattering of electrons off impurities or defects (e.g. dislocations)

Electrical Resistivity of Metals

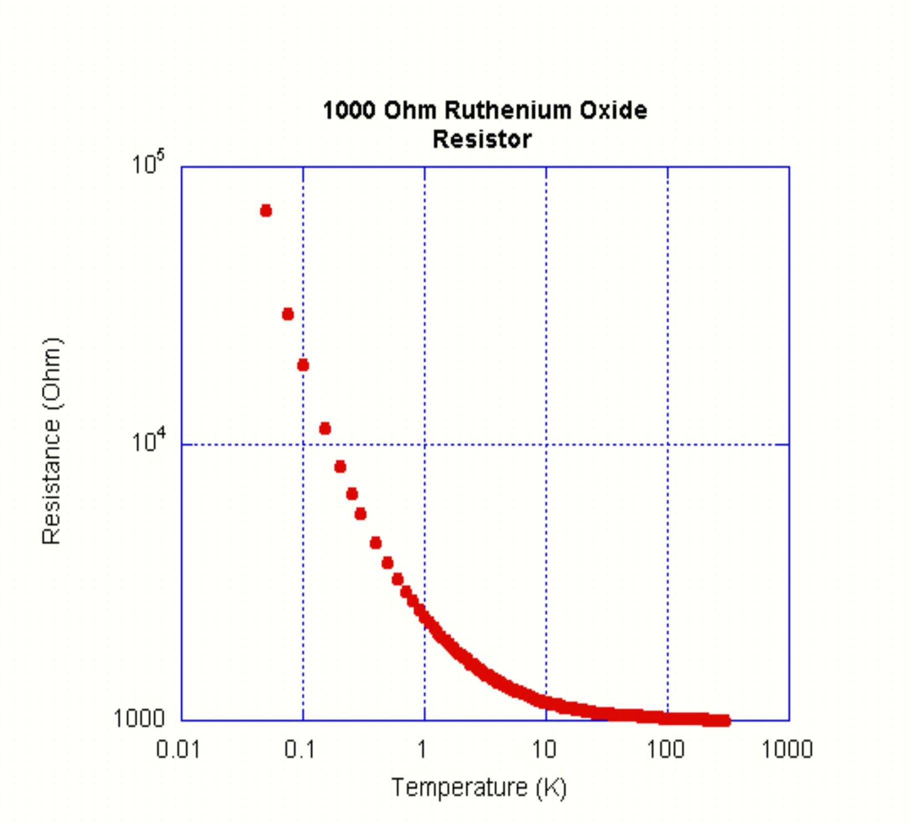
- For T ~ θ phonon scattering dominates
  - ρ is proportional to T
- For T<< θ impurity scattering dominates
  - ρ is constant
- Between these two regions (T~ θ/3)
  - ρ is proportional to T^5 for metals
- RRR = ρ (300 K)/ρ (4.2K) an indication of metal purity

Electrical Resistivity of Copper



Electrical Resistivity of Other Materials

- Amorphous materials & semiconductors have very different resistivity characteristics than metals
- The resistivity of semiconductors is vei decreasing T due to fewer electrons in
- Superconductivity – another course



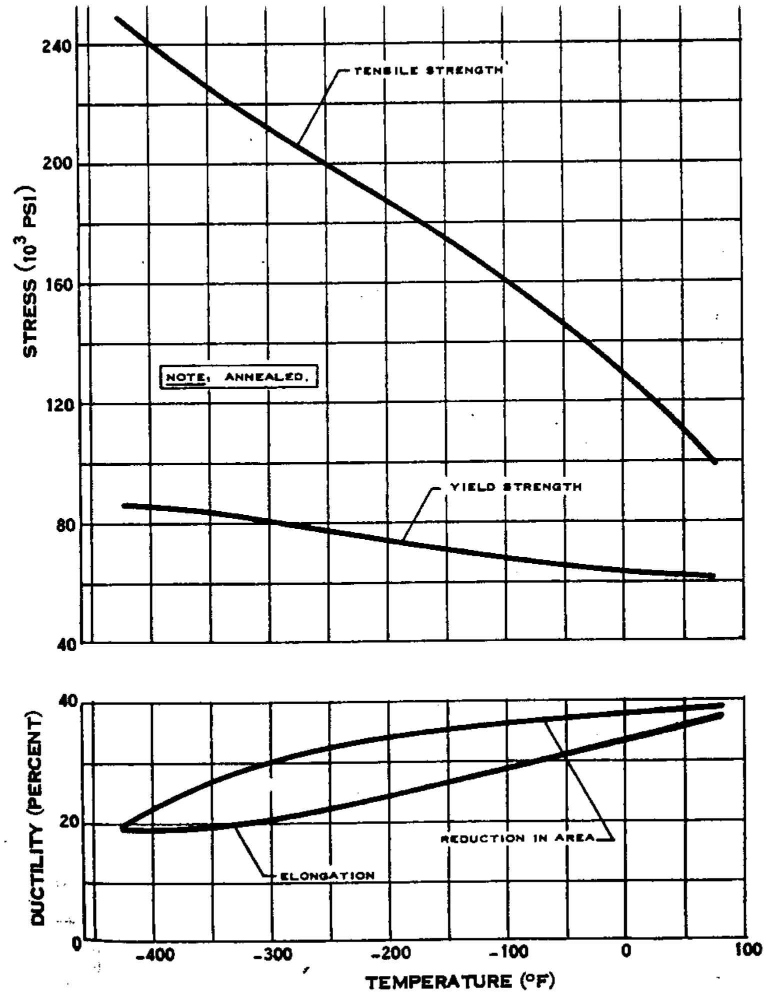
Wiedemann – Franz Law

- In metals, the scattering mechanisms for thermal & electrical conductivity are basically the same
- W-F Law: $K/\sigma = L_0 T$
- L_0 is the Lorenz # $= 2.45 \times 10^{-8}\ W\Omega/K^2$
- This only works at room temp and $T \ll \theta$

Material Strength

- Tends to increase at low temperatures (as long as there is no ductile to brittle transition)
- 300 K values are typically used for conservative design. Remember all systems start out at 300 K & may unexpectedly return to 300 K.
- Always look up values or test materials of interest

Typical Properties of 304 Stainless Steel From Cryogenic Materials Data Handbook (Revised) Schwartzberg et al (1970)



Sources of Data for the Cryogenic Properties of Material

- "A Reference Guide for Cryogenic Properties of Materials", Weisend, Flynn, Thompson; SLAC-TN-03-023 on indico page
- Cryogenic Materials Data Handbook: Durham et al. C13.6/3.961 :
- MetalPak: computer code produced by CryoData

http://www.htess.com/software.htm

- CryoComp: computer Code produced by Eckels Engineering

http://www.eckelsengineering.com/

- I will provide needed properties for exams. If you need properties for the projects and can't find them online please see me.