Other Common Way to Write Ohm's Law

- $J = \sigma E$ or similar to above $E = J/\sigma$
  - neutralizing all the variables for the size of the system
- J is current density: I/A
- σ is conductivity
  - $\sigma = 1/\rho$
  - a material's property- has nothing to do with size & shape of your wire!
- E Electric field strength- is related to force (and voltage)
  - $E = V/L$
  - $F = e E$

Electron Scattering

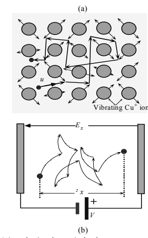

Fig. 2.2: (a) A conduction electron in the electron gas moves about randomly in a metal (with a mean speed u) being frequently and randomly scattered by by thermal vibrations of the atoms. In the absence of an applied field there is no net drift in any direction. (b): In the presence of an applied field, Ex, there is a net drift along the x-direction. This net drift along the force of the field is superimposed on the random motion of the electron. After many scattering events the electron has been displaced by a net distance, Δx, from its initial position toward the positive terminal

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Drift Velocity

$$v_{dx} = \frac{e\tau}{m_e} E_x$$

- stronger field E or smaller mass, bigger v

τ: time between scattering events (mean time between collisions)

$1/\tau$: frequency of getting scattered

$$\mu_d = \frac{e\tau}{m_e}$$ μ; is **drift mobility** $= v_{dx}/E$

Conductivity (or Resistivty) Accounts for Drift Velocity

$$J = \frac{\Delta q}{A\Delta t}$$

$$\Delta q = enA\Delta x = enAv_{dx}\Delta t$$

$$J = \frac{enAv_{dx}\Delta t}{A\Delta t} = env_{dx}$$

$$J = en\mu_d E = \sigma E$$

so $\sigma = e\, n\, \mu$

Temperature Dependence of Resistivity of Metals

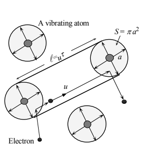

Fig. 2.4: Scattering of an electron from the thermal vibrations of the atoms. The electron travels a mean distance $\ell = u\tau$ between collisions. Since the scattering cross sectional area is S, in the volume $S\ell$ there must be at least one scatterer, $Ns(Su\tau) = 1$.

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$$\tau \propto \frac{1}{\pi a^2} \propto \frac{1}{T}$$

$$= \frac{C}{T}$$

$$\rho_T = \frac{1}{\sigma_T} = \frac{1}{en\mu_D}$$

$$= \frac{m_e T}{e^2 nC} = AT$$

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Mathiessen's Rule

- All these scattering events are accounted for by Mathiessen's Rule

$$\frac{1}{\tau} = \frac{1}{\tau_L} + \frac{1}{\tau_I}$$

$$\frac{1}{\mu} = \frac{1}{\mu_L} + \frac{1}{\mu_I}$$

- $\rho = \rho_L$ (or ρ_T) $+ \rho_I$ (or ρ_R, Residual: due to defects & impurities)

Overall Temperature Dependence of Resistivity

- Unlike scattering due to the lattice, residual resistivity has very little temperature dependence
  - This gives $\rho = AT + B$
  - A comes about from lattice processes, B from residual
- Typically rather than list A & B, they give the TCR (temperature coefficient of resistivity) α_o
  - $\rho = \rho_o [1 + \alpha_o (T - T_o)]$

  ρ_o is the resistivity at a reference T (273K or 293K)

$$\alpha_o = \frac{1}{\rho_o}\left[\frac{\delta\rho}{\delta T}\right]$$

Why is the T Dependence of Iconel, Monel, and NiCr Different Than the Elements??

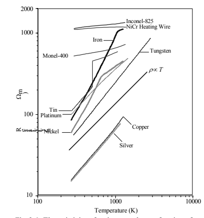

Fig. 2.6: The resistivity of various metals as a function of temperature above 0 °C. Tin melts at 505 K whereas nickel and iron go through a magnetic to non-magnetic (Curie) transformations at about 627 K and 1043 K respectively. The theoretical behavior ($\rho \sim T$) is shown for reference. [Data selectively extracted from various sources including

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Effect of Various Scattering Mechanisms on Resistivity

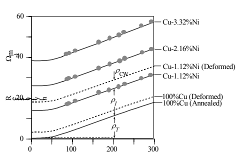

Fig. 2.8: Typical temperature dependence of the resistivity of annealed and cold worked (deformed) copper containing various amount of Ni in atomic percentage (data adapted from J.O. Linde, *Ann. Pkysik*, **5**, 219 (1932)).

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Resistivity Increases with Alloying

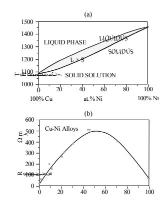

Fig. 2.10:(a) Phase diagram of the Cu-Ni alloy system. Above the liquidus line only the liquid phase exists. In the $L + S$ region, the liquid (L) and solid (S) phases coexist whereas below the solidus line, only the solid phase (a solid solution) exists. (b) The resistivity of the Cu-Ni alloy as a function of Ni content (at.%) at room temperature. [Data extracted from Metals Handbook-10th Edition, Vols 2 and 3, ASM, Metals Park, Ohio, 1991 and Constitution of Binary Alloys, M. Hansen and K. Anderko, McGraw-Hill, New York, 1958]

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What is happening in the Cu-Au system?

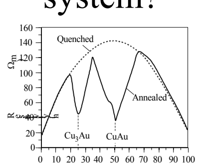

Fig. 2.11: Electrical resistivity vs. composition at room temperature in Cu-Au alloys. The quenched sample (dashed curve) is obtained by quenching the liquid and has the Cu and Au atoms randomly mixed. The resistivity obeys the Nordheim rule. On the other hand, when the quenched sample is annealed or the liquid slowly cooled (solid curve), certain compositions (Cu3Au and CuAu) result in an ordered crystalline structure in which Cu and Au atoms are positioned in an ordered fashion in the crystal and the scattering effect is reduced.

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