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Résumé

(Electronic Transport in Alloys)

Key words:

**Giant Hall effect,
Seebeck coefficient (Thermopower),
Electron density,
Conductivity,
Ioffe-Regel criterion,
Minimum metallic conductivity,
Composites, Nanocomposites**

During the last decades I have derived a series of formulas for calculation of the electronic transport coefficients in composites and disordered alloys. Along the way, some **puzzling phenomenons** have been solved:
1) Why there are simple metals with *positive* thermopower?
2) What is the reason for the phenomenon of the *"Giant Hall effect"* in metal-insulator composites?
3) What is the reason for the fact that *amorphous* metallic composites can *exist*?
4) Is there a lowest Minimum metallic conductivity?

The answer to *1)* is given by the formula (4). The answer to *2)* is given by the formula (5) in connection with (6). The answer to *3)* is given by the formula (5). The answer to *4)* is given by the formulas (10) and (11) following from (9).

The following formulas I have published in:
(1): Phys. Rev. **B 73**, 045126 (2006)
(2): J. Phys.: Condens. Matter **21** (2009) 175703 *and* J. Mater. Chem. C, **4**, 10973 (2016)
(4),(3): J. Phys.: Condens. Matter **22** (2010) 235501
(5): Phys. Rev. **B 40**, 3661 (1989)
(6)-(8): Open J. of Composite Materials **6** (2016) 78
(9): Phys. Rev. **B 71**, 115114 (2005)
(10),(11): Phys.Rev.**B73**, 045126 (2006) (Appendix B)

Thermopower (Seebeck coefficient) for alloys with phase separation (*composites*)

$$\sum_i v_i \frac{\sigma_i/S_i - \sigma/S}{\sigma_i/S_i + 2\sigma/S} \approx 0 \tag{1}$$

$$\sum_i v_i \frac{\kappa_{e,i}/S_i - \kappa_e/S}{\kappa_{e,i}/S_i + 2\kappa_e/S} = 0 \tag{2}$$

where S_i is given by

$$S_i = S_{i,0} + \frac{1}{|e|}\frac{d\mu}{dT}. \tag{3}$$

Thermopower in *homogeneous* alloys

$$S = S_0 + \frac{1}{|e|}\frac{dE_c}{dT} \tag{4}$$

S_0 is the *classical* thermopower formula for a homogeneous alloy. ($S_{i,0}$ is the *classical* thermopower formula for the phase i.) The additional term in (4), "$\frac{1}{|e|}\frac{dE_c}{dT}$", follows as limiting case of (2) for an one-phase alloy. It is the reason for *positive* Seebeck coefficient of many metals, for instance: Cu, Ag, Au, Li.

Electron density in alloys with *amorphous phase separation* (electron transfer between the phases)

$$dn = -\beta \cdot n \cdot d\zeta \tag{5}$$

Hall coefficient formula for *two-phase composites*

$$R = \frac{\sigma_A^2 R_A\left[\sigma_B + \sigma(3v_A - 1)\right] + \sigma_B^2 R_B\left[\sigma_A + \sigma(3v_B - 1)\right]}{\sigma(\sigma_A\sigma_B + 2\sigma^2)} \tag{6}$$

General Hall coefficient formula for *composites* with two or more phases

$$\left(R\sigma^2\frac{\partial}{\partial\sigma} + \sum_i R_i\sigma_i^2\frac{\partial}{\partial\sigma_i}\right) f(\sigma,\sigma_i) = 0, \tag{7}$$

where

$$f(\sigma,\sigma_i)=\left(\prod_i(\sigma_i+2\sigma)\right)\left(\sum_i \upsilon_i\frac{\sigma_i-\sigma}{\sigma_i+2\sigma}\right) \quad (8)$$

Ioffe-Regel criterion (Alternative interpretation)

$$k_F L \geq c^* = \frac{1}{4} \quad (9)$$

Minimum metallic conductivity; *strong scattering*

$$\sigma_{min}=\frac{c^{*2}}{6}\left(\frac{\mathrm{e}^2}{h}\right)\frac{1}{d}=\frac{1}{96}\left(\frac{\mathrm{e}^2}{h}\right)\frac{1}{d} \quad (10)$$

Minimum metallic conductivity; *general case*

$$\sigma_{min}=\frac{2c^{*2}}{3\pi}\left(\frac{\mathrm{e}^2}{h}\right)\frac{1}{L}=\frac{1}{24\pi}\left(\frac{\mathrm{e}^2}{h}\right)\frac{1}{L} \quad (11)$$

Symbols

S - Seebeck coefficient
σ - electrical conductivity
κ_{e} - electronic contribution to the thermal conductivity
υ_i - volume fraction of the phase i
i characterizes the phase in a composite, $i = A, B, \ldots$
R - Hall coefficient
n - electron densitiy [in a two-phase composite n is the electron densitiy in the phase with the higher potential ($\equiv$ phase A)]
$\zeta = \upsilon_B/\upsilon_A$
β - a constant for a given alloy, which is determined by the average potential difference between the two phases.
E_c - band edge of the conduction band
T - temperature
μ - electrochemical potential
k_F - wave number at the Fermi surface
L - mean free path of the electronic carriers
d - average atomic distance