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Resistivity of metallic systems with a strong dynamic disorder

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Abstract. If the static disorder in a system is increased the conductivity and the electron mean free path decreases to the limit where it reaches the Ioffe-Regal criterion. In this paper experimental results are presented which show that dynamic disorder (produced by electron-phonon interaction) can produce similar effects as static disorder. In certain metallic glasses it has been found that when the resistivity as a function of temperature reaches a critical value (almost equal to the maximum metallic resistivity value) the TCR changes from positive to negative values.

Keywords. Resistivity; metallic systems; dynamic disorder.

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1. Introduction

In accordance with the known Ioffe-Regel criterion the electronic mean free path, l, cannot be shorter than the electron wavelength. When applied to the metals with the Fermi momentum K_F this means that

$$l > l_{\min} \approx \pi/K_F. \tag{1}$$

The metallic systems with l approximating $l_{\min}$ are extensively being studied in the last few years due to the progress achieved in the technique of producing amorphous alloys. Mostly the small mean free path l is the consequence of the static disorder, i.e. random arrangement of atoms at low temperatures. On the other hand, the smallest possible l can also be obtained in some cases in a perfect crystal by increasing the temperature T, i.e. by introducing the dynamic disorder.

2. Comparison between static and dynamic disorders

Let us refer to the plane $(T, \hbar/\tau)$ with the Fermi energy ε_F on both the axes as a characteristic scale (figure 1). The condition of the degeneracy of the electron gas $T < \varepsilon_F$, along with the uncertainty relation

$$\Delta\varepsilon \approx \hbar/\tau \lesssim \varepsilon_F = \hbar^2 K_F^2/2m \tag{2}$$

which isolate a square in this plane (criteria (1) and (2) actually are equivalent, differing in the numerical factor $\pi/2$ only). The formula for the resistivity

$$\rho = m/ne^2\tau = \hbar K_F/ne^2 l, \tag{3}$$