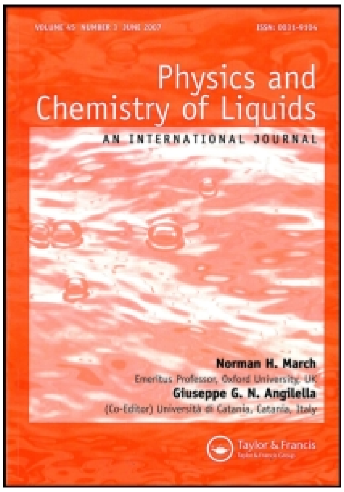

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Letter

RELATION BETWEEN ELECTRICAL RESISTIVITY AND NUCLEAR RELAXATION RATE IN METALLIC STATES FOR BOTH FERMI- AND NON-FERMI-LIQUID PHASES

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Fermi-liquid theory in two dimensions, for electron or hole liquids flowing through antiferromagnetic assemblies, yields $RT_1 \propto T$, where R is the electrical resistivity and T_1^{-1} the nuclear relaxation rate. This relation holds over an appropriate temperature range for Cu spins in underdoped high T_c cuprates. Here a non-Fermi-liquid phase of a strongly disordered metallic spin glass is pointed out to exhibit a relation $RT_1 \propto T^n$, again over a restricted temperature range, where the exponent n has the meanfield value of 5/4.

Keywords: Two dimensional fermi liquid; metallic spin glass; non-fermi-liquid phase

In earlier studies [1,2], strongly correlated electron liquids of very different characters have been studied and relations established between electrical transport properties and magnetic susceptibility. Two specific systems that were focussed on were (i) the heavy liquid alkali metal Cs taken up the liquid-vapour coexistence curve towards the critical point[3,4] and (ii) the high T_c cuprates in the normal state[5]. In both systems (i) and (ii), a relation between electrical resistivity R and magnetic susceptibility χ emerged[1,2,4].

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The specific focus of this Letter will be to relate electrical resistivity R to nuclear relaxation rate T_1^{-1}, the latter reflecting the low-frequency dynamics of spin fluctuations. For orientation, let us summarize the relation pointed out by Egorov and March [2] for underdoped high T_c cuprates in the normal state. The motivation for their relation (eqn (3) below) was the two-dimensional Fermi-liquid study by Kohno and Yamada [6], who were concerned with carriers in antiferromagnetic assemblies. If χ ($\mathbf{Q}$) denotes the magnetic susceptibility of the Cu spins in the high T_c cuprates at the antiferromagnetic wave vector $\mathbf{Q}$, then Kohno and Yamada showed from Fermi-liquid theory that

$$R \propto \chi(\mathbf{Q})T^2 \qquad (1)$$

and

$$(T_1 T)^{-1} \propto \chi(\mathbf{Q}) \qquad (2)$$

Eliminating $\chi(\mathbf{Q})$ between eqns (1) and (2), the Cu nuclear spin-lattice relaxation time T_1, multiplied by the electrical resistivity R, is directly proportional to the temperature[2]:

$$RT_1 \propto T. \qquad (3)$$

Over a restricted temperature range [7], Egorov and March [2] found agreement between eqn (3) and experimental data of Bucher *et al* [5] on an underdoped cuprate.

Here we shall compare and contrast the above system with that of a non-Fermi-liquid phase, considered by Sachdev, Read and Oppermann [8] and by Sengupta and Georges [9]. In both these studies [8,9] in the non-Fermi-liquid regime of a metallic spin glass, scaling relations were found in a fully developed mean-field theory [8,9] which can be summarized as follows:

(a) Magnetic susceptibility $\chi(T)$ has the form

$$\chi(T) - \chi(0) \equiv \Delta\chi \propto T^{3/4}. \qquad (4)$$

(b) Electrical resistivity R behaves as

$$R \propto T^{3/2} \qquad (5)$$

while the relaxation rate T_1^{-1} of nuclei coupled to the electronic spins by a hyperfine coupling obeys the relation [9]

$$(c)(T_1 T)^{-1} \propto T^{-3/4}. \tag{6}$$

Focussing immediately on the analogue of eqn (3) above obtained for high T_c cuprates from two-dimensional Fermi-liquid theory, one finds from eqns (5) and (6) the result

$$RT_1 \propto T^{5/4}. \tag{7}$$

Thus, in this specific system: a metallic spin glass in its non-Fermi-liquid regime [8,9], mean-field theory yields the exponent 5/4 in the temperature dependence of the product of electrical resistivity R and nuclear relaxation time T_1.

Using the scaling arguments in refs 8 and 9: see also ref 10, one can effect some generalization of the mean-field results (4)–(7) in the non–Fermi-liquid regime of a metallic spin glass. Thus we can write, using scaling relations proposed in refs 8–10,

$$RT^{-2} \propto T^{2\Gamma}, (T_1 T)^{-1} \propto T^{2\Gamma\tau}, \quad \Delta\chi \propto T^{(2\Gamma+1)\tau}. \tag{8}$$

In the scaling behaviour (8), the mean-field (mf) results [8–10] (4)–(7) above are recovered by setting $\Gamma_{mf} = -(1/4)$ and $\tau_{mf} = (3/2)$.

From eqns (8), one finds

$$(T_1 T)^{-1} \propto (RT^{-2})^{\tau}. \tag{9}$$

It would be of obvious interest for the future to make a ln-ln plot from experiment of $(T_1 T)^{-1}$ vs (RT^{-2}) to test in the non-Fermi-liquid regime of a metallic spin glass how the exponent τ in eqn (9) deviates from its *mf* value $\tau_{mf} = (3/2)$. More directly related to eqn (7) :

$$RT_1 \propto T^n \tag{10}$$

where $n = [2\Gamma(1-\tau)+1]$. Again a test of the accuracy of the *mf* estimate $n_{mf} = 5/4$ would be of interest.

In summary, in both examples presented here for Fermi-liquid (two dimensions : eqn (3)) and non-Fermi-liquid phases (eqns (7) and (9)), there is an intimate relation between electrical resistivity R and nuclear relaxation rate T_1^{-1} over a restricted range of temperature. Further experimental work on both high T_c cuprates (two-dimensional case) and also on the non-Fermi-liquid regime of metallic spin glasses would clearly be of value in exploring the range of validity of these predicted relations between R and T_1^{-1}.

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