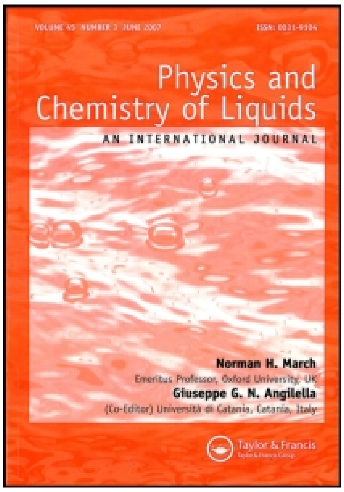

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LETTER

Transport Properties of Electron or Hole Liquids in Normal State of High T_c Copper Oxides

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In earlier work on strongly correlated liquid metals, taken along the liquid-vapour coexistence curve towards the critical point, a relation between a transport property, electrical resistivity, and a thermodynamic quantity, magnetic susceptibility, has been demonstrated.

This same type of correlation is pressed here for electron or hole liquids flowing through antiferromagnetic assemblies in the normal state of some high T_c copper oxide materials. Elimination of magnetic susceptibility in a Fermi liquid framework then leads to the prediction that electrical resistivity is intimately linked with nuclear spin–lattice relaxation time and empirical data is employed to test this relation.

Finally, experiments on Hall constant and thermopower are also briefly referred to.

KEY WORDS: Resistivity, nuclear spin–lattice relaxation time.

In earlier work [1,2] strongly correlated electron theory has been employed to treat liquid alkali metals along the liquid–vapour coexistence curve towards the critical point. The important point to be emphasized in the present context is that this led, rather directly, to a demonstration from experimental data of an intimate link between a transport property, namely electrical resistivity, and a thermodynamic quantity; magnetic susceptibility [2].

Concerning high T_c copper oxides, one of us [3] has recently emphasized, in a related context, the importance for the properties of the electron or hole liquids in the normal state that these are flowing through antiferromagnetic assemblies of copper spins. To press in this case the correlation referred to above between electrical resistivity and magnetic susceptibility, a useful starting point for our present considerations is afforded by the Fermi liquid study of Kohno and Yamada [4]. These workers link the electrical resistivity R with the magnetic susceptibility $\chi(\vec{Q})$, where $\vec{Q}$ is the antiferromagnetic wave vector. In particular, the analysis of Kohno and Yamada leads to the proportionality

$$R \propto T^2 \chi(\vec{Q}). \tag{1}$$

They note then that if the further assumption is made of Curie-Weiss form $C/(T+\Theta)$ for $\chi(\vec{Q})$, with $\Theta > 0$ then one has for $T \gg \Theta$ that $R \propto T$ which is an experimental finding over a substantial range of temperature in the normal state of high T_c superconductors (see, for example, Figure 3 of ref. 3).

The first aim of the present work is to test the form (1) of Kohno and Yamada by linking it with a quite different property, namely the nuclear spin–lattice relaxation time T_1 at copper sites. The above workers use their same Fermi liquid analysis to link T_1 with $\chi(\vec{Q})$ via

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

Substituting the form $\chi(\vec{Q})$ in Eq. (2) into Eq. (1) one is led to the further prediction

$$R T_1 \propto T \qquad (3)$$

and experimental values [5] of R and T_1 for $YBa_2Cu_4O_8$ have been used to construct Figure 1. The linear relation between RT_1 and temperature is well borne out in Figure 1 over a temperature range from 150–450 K. However, there is a major new feature of a minimum around 100 K and this raises the question as to the validity of Fermi liquid theory in this lower temperature range.

We turn finally to some briefer comments on the Hall coefficient R_H and on the thermopower. Returning to the introductory points made on strongly correlated

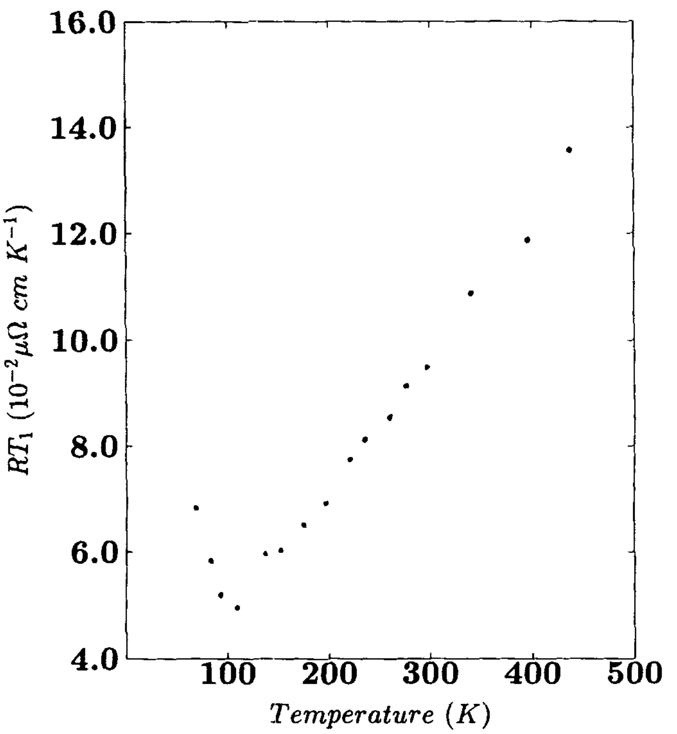

Figure 1 Plot of Eq. (3) from experimental values [5]. (Note at proof. Dimensions of ordinate are $\mu\Omega$ cm s)

electrons in the liquid alkalis approaching criticality, one of us [6] has argued, again from Fermi liquid theory, that the Hall coefficient R_H is itself closely connected with electrical resistivity R. However, though Kohno and Yamada [7] have given a general expression for the Hall coefficient based on Fermi liquid theory, the situation is not, it would appear, sufficiently well understood to lead to an immediate relation to $\chi(\vec{Q})$ in Eqs. (1) and (2). Therefore we shall here content ourselves with showing, by means of Figure 2, that the various curves [8,9] of R_H have some salient and related properties. If, as noted in ref. 3, for example, one considers R_H^{-1} instead of R_H then the slope of R_H^{-1} correlates with the superconducting transition temperature T_c. Figure 3 finally shows experimental data [10] on the thermopower in high T_c materials. Here we also note a major change in behaviour, the maxima again occurring in the temperature range around 100–150 K.

In summary, Fermi liquid theory for treating electron or hole liquids flowing through antiferromagnetic assemblies created by the copper spins leads to the prediction (1) for the electrical resistivity. For a quite different property, the nuclear spin–lattice relaxation time T_1, a link also can be forged [4] with $\chi(\vec{Q})$. Eliminating $\chi(\vec{Q})$ leads us, using experimental data [5], to the plot shown in Figure 1. While further transport data show related crossover behaviour as in Figures 2 and 3, a deeper theoretical understanding of Hall coefficient and thermopower is plainly a challenge for the future.

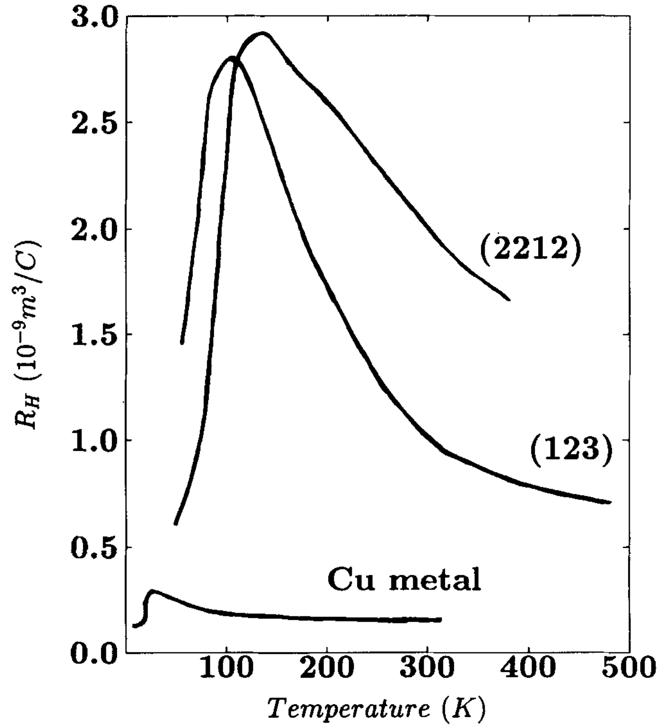

Figure 2 Hall coefficient R_H vs temperature from experiment [8,9].

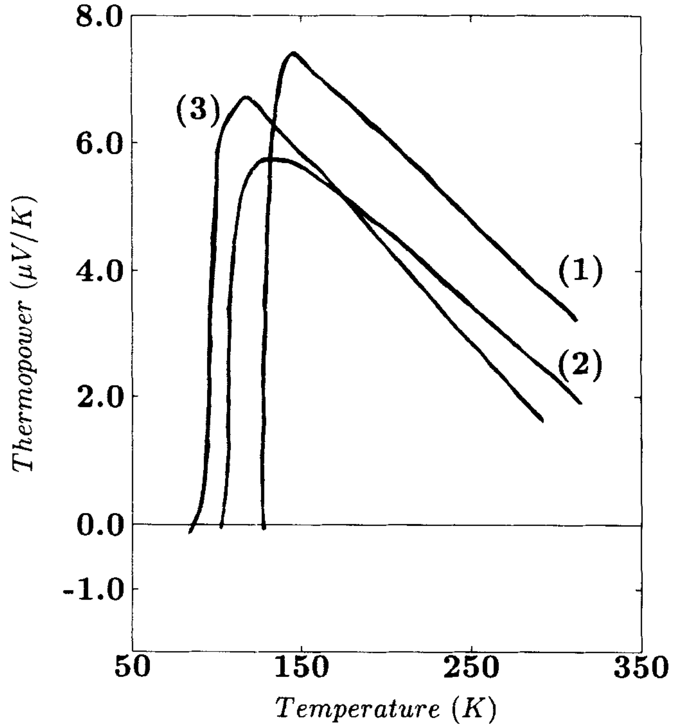

Figure 3 Experimental data [10] on thermopower.

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