ELSEVIER

Physica B 312–313 (2002) 793–794

PHYSICA B

www.elsevier.com/locate/physb

Can fractional power-law conductivity explain the deviations from Matthiessen's rule in $SrRuO_3$?

Y. Kats, L. Klein*

Physics Department, Bar-Ilan University, Ramat-Gan 52900, Israel

Abstract

In a recent work on the optical conductivity of the ferromagnetic metal $SrRuO_3$ it was suggested that its electrical DC conductivity σ might not be proportional to the scattering time τ, but to some fractional power of it: $\sigma \propto \tau^{\alpha}$ with $\alpha \simeq 0.4$. We examine whether this empirical law can account for the unusual deviations from Matthiessen's rule found in this compound. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Ruthenates; Matthiessen's rule; Non-Fermi-liquid behavior

We have recently shown [1] that when defects are added (by electron irradiation) to samples of the metallic compounds $SrRuO_3$ and $CaRuO_3$, the change in the resistivity is temperature-dependent. This is in contrary to the usual assertion, based on Matthiessen's rule, that the contribution of defects to resistivity of metals is temperature-independent. Furthermore, deviations from this rule usually result in a resistivity change which *increases* as a function of temperature (and then can be attributed to the varying intensity of the different scattering mechanisms over an anisotropic Fermi surface [2]), while in $SrRuO_3$ and $CaRuO_3$ the change in resistivity *decreases* with temperature.

We suggested an interpretation to this behavior, based on the notion that the short mean free path and the high anisotropy of the Fermi surface in $SrRuO_3$ and $CaRuO_3$ amplify effects related to the Pippard ineffectiveness condition, according to which scatterers with $q < 2\pi/\lambda$ (where λ is the mean free path of the electron) are not effective in scattering. We found that the estimated magnitude of the expected effect agrees with the experiment. The details are given in Ref. [1], and more information on these metals which attract much interest in recent years can be found in Refs. [3–11] ($SrRuO_3$) and [10–12] ($CaRuO_3$).

*Corresponding author. Tel.: +972-3-531-7861; fax: +972-3-53-53-298.

E-mail address: kleinl@mail.biu.ac.il (L. Klein).

While Pippard ineffectiveness condition provides a satisfactory explanation for the deviations from Matthiessen's rule in $SrRuO_3$, here we examine the possibility of an alternative interpretation for these results. In a recent work [8], it was suggested that the behavior of the optical conductivity in $SrRuO_3$ implies that its electrical DC conductivity σ is not proportional to the scattering time τ as in Fermi-liquid metals, but instead follows a relation of the form $\sigma \propto \tau^{\alpha}$ with $\alpha \simeq 0.4$. In the following we ask whether this relation can account for our results.

Assuming that the resistivity $\rho = 1/\sigma$ behaves as

$$\rho = \frac{C}{\tau^{\alpha}}, \tag{1}$$

where C is a constant, and that the scattering time τ after adding some amount of defects is given by

$$\frac{1}{\tau(T)} = \frac{1}{\tau_0(T)} + \frac{1}{\tau_{\rm def}}, \tag{2}$$

where τ_0 is the original scattering time and $\tau_{\rm def}$ is the (temperature-independent) scattering time related to the added defects, then the change in resistivity is

$$\Delta\rho(T) = \left[\sqrt[\alpha]{\rho_0(T)} + \sqrt[\alpha]{\rho_{\rm def}}\right]^{\alpha} - \rho_0(T), \tag{3}$$

where $\rho_0(T)$ is the original resistivity, and $\rho_{\rm def} = C/\tau_{\rm def}^{\alpha}$ does not depend on temperature. Inserting in Eq. (3) the experimental values of $\rho_0(T)$ and $\Delta\rho(0)$, we can calculate

0921-4526/02/$ - see front matter
PII: S0921-4526(01)01226-1

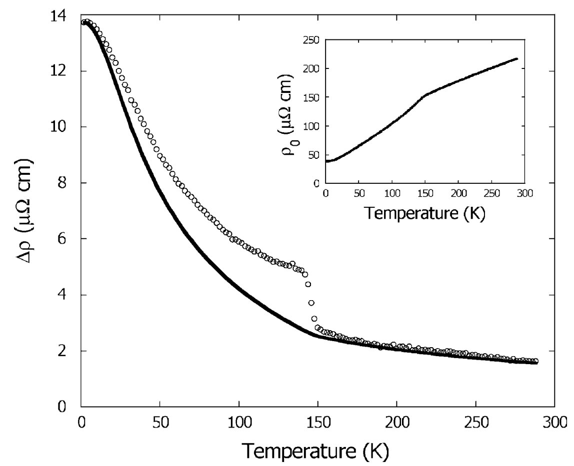

Fig. 1. Plot of the experimental $\Delta\rho(T)$ (circles) and the prediction of Eq. (3) with $\alpha = 0.42$ (solid line). The parameter $\rho_{\rm def}$ was determined from the value of $\Delta\rho$ at low temperature. The original resistivity $\rho_0(T)$ is shown in the inset.

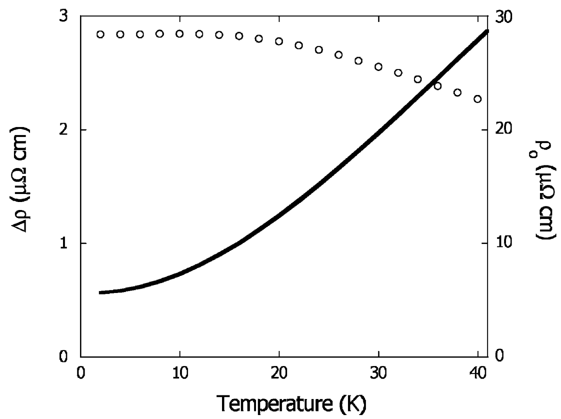

Fig. 2. Behavior of $\Delta\rho$ (circles, scale on the left) and ρ_0 (solid line, scale on the right) as a function of temperature in a sample with a low residual resistivity.

the full temperature dependence of $\Delta\rho$ and compare it with the experimental results.

Fig. 1 shows the experimental and the calculated $\Delta\rho(T)$ for one of our samples. The agreement for this sample seems quite satisfactory, except for the feature in the middle of the temperature range, including a sharp "step down" in the experimental $\Delta\rho$. This feature is related to the ferromagnetic phase transition ($T_C \sim 150$ K), and its origin is discussed in Ref. [1].

The picture is different when we examine a sample with much lower residual resistivity, for which Eq. (3) does not reproduce the results. Fig. 2 shows $\Delta\rho(T)$ and $\rho_0(T)$ for such a sample. We observe that while $\rho_0(T)$ increases fast at low temperatures, $\Delta\rho(T)$ is almost constant. Eq. (3) allows $\Delta\rho(T)$ to remain almost unchanged despite significant changes in $\rho_0(T)$ only if $\rho_{\rm def} \gg \rho_0(T)$, but this condition implies $\Delta\rho(T) \gg \rho_0(T)$, which is not true in this case.

The failure of Eq. (3) for the sample with the low residual resistivity (particularly at low temperatures) may indicate that the fractional power law $\sigma \propto \tau^\alpha$ cannot describe the deviations from Matthiessen's rule. On the other hand, one could say that the existence of the fractional power law depends on the presence of a sufficient amount of disorder, as in the samples examined in Ref. [8]. This is supported by the observation [6] that low-residual-resisitivity samples of $SrRuO_3$ exhibit Fermi-liquid-like behavior, such as Shubnikhov–de Haas oscillations below 1 K and resistivity with a T^2 dependence up to 10 K, while their high-frequency optical conductivity above 40 K strongly deviates from Fermi-liquid behavior (it falls with frequency like $1/\omega^{1/2}$ [5] instead of the $1/\omega^2$ dependence expected for a Fermi liquid).

In conclusion, while fractional power-law conductivity cannot provide a comprehensive description of the deviations from Matthiessen's rule in $SrRuO_3$, it may still give a plausible description in some range of parameters. To further test this suggested link between deviations from Matthiessen's rule and fractional power-law conductivity, it would be interesting to measure the optical conductivity of $CaRuO_3$, whose deviations from Matthiessen's rule show a similar behavior [1]. On the other hand, it would be also interesting to examine whether the Pippard ineffectiveness condition, which was successful [1] in explaining the deviations from Matthiessen's rule, can also account for the anomalous behavior of the optical conductivity in $SrRuO_3$.

We thank J. S. Dodge, S. Levy and N. Wiser for helpful discussions. This research was supported by the Israel Science Foundation founded by the Israel Academy of Sciences and Humanities and by Grant No. 97-00428/1 from the United States-Israel Binational Science Foundation (BSF), Jerusalem, Israel.

References

[1] L. Klein, et al., Europhys. Lett. 55 (2001) 532.
[2] J.M. Ziman, Electrons and Phonons, Clarendon Press, Oxford, 1960, pp. 285–287.
[3] P.B. Allen, et al., Phys. Rev. B 53 (1996) 4393.
[4] L. Klein, et al., Phys. Rev. Lett. 77 (1996) 2774.
[5] P. Kostic, et al., Phys. Rev. Lett. 81 (1998) 2498.
[6] A.P. Mackenzie, et al., Phys. Rev. B 58 (1998) R13318.
[7] J.S. Dodge, et al., Phys. Rev. B 60 (1999) R6987.
[8] J.S. Dodge, et al., Phys. Rev. Lett. 85 (2000) 4932.
[9] Y. Kats, et al., Phys. Rev. B 63 (2001) 054435.
[10] G. Cao, et al., Phys. Rev. B 56 (1997) 321.
[11] G. Santi, T. Jarlborg, J. Phys.: Condens. Matter 9 (1997) 9563.
[12] L. Klein, et al., Phys. Rev. B 60 (1999) 1448.