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THE ELECTRICAL RESISTIVITY OF LIQUID LEAD

M. Stojić, B. Babić
"Boris Kidrič" Institute of Nuclear Sciences
Vinča, Belgrade

Abstract: The electrical resistivity of liquid lead has been investigated in the temperature range from the melting point (600 K) to 860 K. It has been established that the resistivity is a linear function of temperature dependent on the concentration of impurities. Experimental results were compared with other published values and with the theoretical values calculated in the framework of the Ziman theory.

1. Introduction

The electrical resistivity of liquid lead has been so far investigated by several groups of authors(1,2). The resistivity data obtained in these experiments are in good agreement and show linear temperature dependence of resistivity in the measured range from the melting point (600 K) up to 1300 K. Moreover, abrupt change in the temperature coefficient of resistivity has been found by one group of workers1) at the particular temperature (666 K). But in this work, where two purities of lead were investigated (99.999% and 99.98%), the authors did not observe the dependence of resistivity on the sample purity.

The purpose of the present work is, therefore, to check the resistivity data of liquid lead found in the previous works and to investigate the dependence of resistivity on the concentration of impurities.

2. Experimental

The resistivity was measured by DC potentiometric method in specially constructed apparatus, the main part of which is shown in fig. 1.

After melting in an inert atmosphere, liquid lead was introduced in the U-profile quartz cell consisting of four side capillaries. Two of them (8) are current lead electrodes and other twO (9) are potential electrodes. Solid lead in the parts of capillaries outside the electrical furnace, was used to obtain the contacts with DC measurement current source and also with the potentiometric system. In order to minimize thermal e.m.f.'s, the ends of capillaries were locally thermalised at 20°C. The effect of small thermal e.m.f.'s and other parasitic potentials in circuit was corrected by performing the measurements in both current directions.

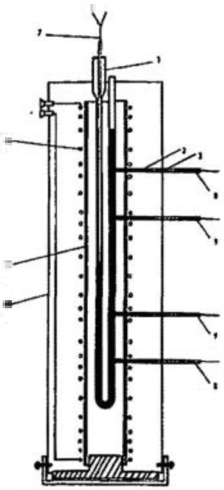

Fig. 1. The apparatus for measuring $\rho = f(T)$ of liquid metals: 1 - quartz cell; 2 - liquid metal; 3 - solid metal; 4 - electric heater; 5 - heater holder; 6 - furnace body; 7 - thermo-couple; 8 - current lead electrodes; 9 - potential electrodes.

In the direct method of resistivity measurements used in the present work it is necessary to know the geometrical factor of quartz cell. It was determined by resistivity calibration with mercury at room temperature. In all experiments, the random scatter in the resistivity data was less than ±0.15% and the absolute accuracy of the data were estimated to be better than ±0.5%.

3. Results and discussion

In our experiment liquid lead of three grade of purity has been investigated, 99.9999% pure, 99.9% pure and tin doped lead with approximately 1% tin concentration.

The results of resistivity measurements on the high purity lead (the 99.9999% pure) are shown in fig. 2 (curve 1).

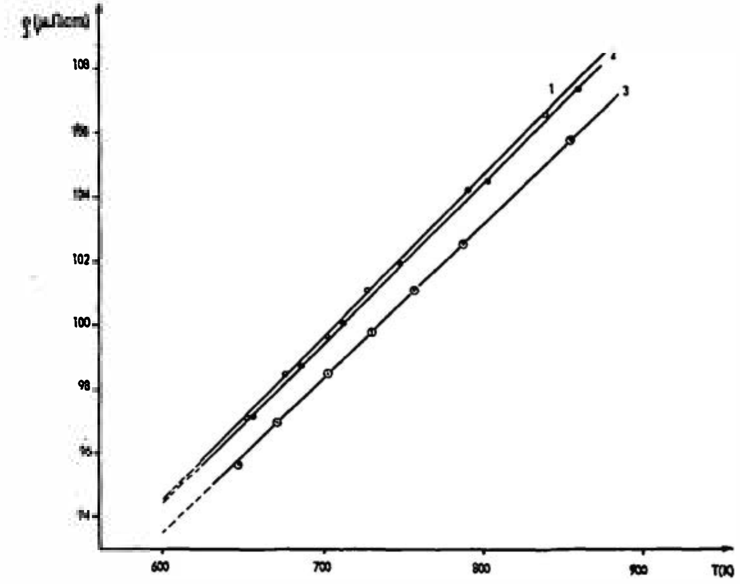

Fig. 2. Resistivity of liquid lead as a function of temperature: 1)99.9999% Pb; 2) 99.9% Pb; 3) 1% tin doped Pb.

Its resistivity was found to be a linear function of temperature in the whole measured range which has been described by the following relation (obtained by the method od least squares):

$$\rho = 64.56 + 0.050\ T\ \mu\Omega cm.$$

where T is the temperature in K.

The temperature coefficient of resistivity $\frac{\partial \rho}{\partial T}$ is $0.050.10^{-6}$ΩcmK^{-1} and the resistivity at the melting point (600 K) determined by linear extrapolation of the data is 94.57μΩcm

The results of the measurements on the lower purity lead (the 99.9% pure) are shown as curve 2 in fig. 2. It has been observed that the resistivity of the 99.9% lead was also a linear function of temperature but although the difference between the resistivity values of the pure lead and that of the less pure lead was only about 0.2%, the resistivity of the 99.9% lead was consistently lower in the whole investigated range.

This result was the indication of the resistivity of liquid lead being dependent on impurity concentration. In order to confirm such dependence, the measurements have also been performed on the tin doped lead with approximately 1% tin concentration. As it had been expected because of the higher impurity concentration and because of the resistivity of liquid tin which was about 47μΩcm at the melting point (505 K), the resistivity of the tin doped lead was shifted towards the lower values with respect to the resistivity of the pure lead and this shift amounts about 1.2% (curve 3 in fig. 2).

The temperature dependence of the 99.9% lead is given by the relation:

$$\rho = 64.70 + 0.0495\ T \mu\Omega\text{cm}$$

and that of the tin doped lead:

$$\rho = 65.04 + 0.0475\ T \mu\Omega\text{cm}$$

We compared our resistivity values obtained in the high purity lead (the 99.9999% pure) with the experimental results of Davies and Llewelyn Leach1) and of Roll and Motz2). The agreement between these results is satisfactorily good. The resistivity extrapolated to the melting point in our measurements is 94.57μΩcm which is close to the values 94.85μΩcm1) and 95.0μΩcm2) and all other values fall into the limits of accuracy of our measurements (±0.5%).

The Ziman theory appears to be successful in explaning the electrical resistivity and thermoelectric properties of liquid metals. The agreement between the experimental observations and the predictions of Ziman's theory depends not only on the accuracy of the liquid metal structure factors and the ionic pseudopotentials but also on the accuracy of a number of approximations and limitations involved[5].

The Ziman theory has been applied recently in calculations of liquid lead resistivity as a function of temperature[3]. These calculations were performed on the basis of the experimental structure factor data[4], two different pseudopotential form-factors (the general model pseudopotential form-factor[5,6] and the Heine-Abarenkov pseudopotential form-factor[7])and two different screening functions (Hartree and Geldart-Vosko dielectric function).

The results of these calculations are shown in fig. 3 together with our experimental results. As it can be seen, the best agreement between the calculated resistivity and experiments was obtained for the general model pseudopotential form-factor, experimental structure factor and Hartree dielectric function (curve 2).

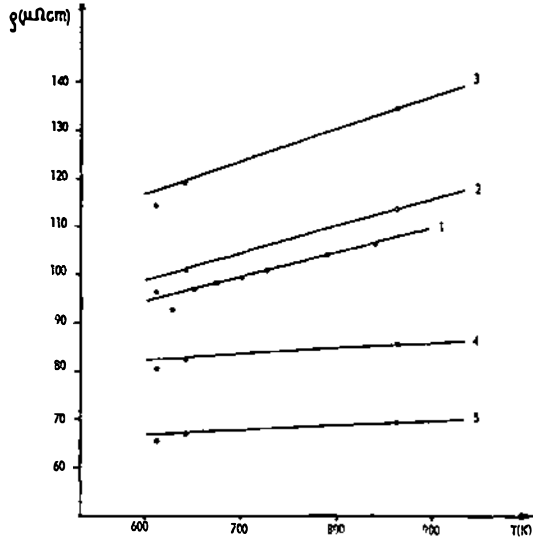

Fig. 3. Resistivity values of liquid lead:
1- Experimental results of present work; other curves represent the calculated values on the basis of experimental structure factor; 2 - general model pseudopotential form-factor and Hartree dielectric function; 3 - the same pseudopotential form-factor and Geldart-Vosko dielectric function; 4 - and 5 - Heine Abarenkov pseudopotential form-factor with Geldart-Vosko and Hartree dielectric function respectively.

In liquid metals such as Pb in which the electron mean free path is short, a correction of Ziman's formula has to be considered. Although these corrections are usually small and are neglected, a rough estimation of this correction performed in this work suggests that the calculated resistivity values of liquid lead should be by about 10% smaller.

References

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