EXPERIMENTAL STUDY OF THERMAL CONDUCTIVITY AND ELECTRICAL RESISTANCE OF CERTAIN BINARY ALLOYS OF THE SYSTEM Pb–Bi IN THE LIQUID STATE

R. E. Krzhizhanovskii, N. P. Sidorova, and I. A. Bogdanova

UDC 536.21

Experimental results are presented for measurement of thermal conductivity in the temperature range from fusion to 500°C and for electrical resistance from fusion to 900°C. The experimental Lorentz number is calculated and properties are presented as functions of composition.

In various branches of industry liquid-metal heat-exchange media are finding ever wider use. Such heat exchangers have a number of advantages as compared to others.

The basic requirements for a heat-exchange medium are the following: 1) high heat-exchange intensity; 2) low melting temperature; 3) high boiling temperature; 4) inability to corrode construction materials; 5) high thermal stability; 6) low cost.

Of the heavy low-melting-point metals the most promising for use as a heat-exchange medium in power apparatuses are alloys based on lead and bismuth. Of special significance is the lead–bismuth eutectic alloy.

To determine the general principles governing behavior of thermal conductivity and electrical resistance of alloys of the lead–bismuth system, the present study investigated a number of alloys and the original materials.

The alloys were prepared by melting of lead and bismuth with thorough mixing in an argon atmosphere. Then the alloys were poured into containers of 1Kh18N10T steel and samples taken for chemical analysis. The containers were argon-arc welded. Before the experiment the alloys in their containers were maintained at a temperature of 500-600°C no less than 4 h (specimens for thermal-conductivity measurements) and at a temperature of 700-800°C no less than 1 h (specimens for electrical-resistance measurements).

Thermal conductivity was measured by the plane-layer stationary method described in [1] to an accuracy of ±10%, while electrical resistance was measured by the compensation method to ±1.5% with an apparatus constructed by the authors and described in [2].

Results of thermal-conductivity and electrical-resistance measurements, as well as Lorentz number values calculated from these data, are presented in Fig. 1 as functions of temperature.

The thermal conductivity of lead–bismuth alloys has a positive temperature coefficient and varies significantly from alloy to alloy. The basic role in heat transfer in the fused state, as in lead–tin [3] and eutectic bismuth–tin [2] alloys, is played by electrons. The atomic heat conductivity of lead, bismuth, and their alloys comprises less than 1% of the total heat conductivity.

Electrical resistance of the alloys increases with addition of bismuth to lead and has a positive temperature coefficient, which changes from alloy to alloy not more than 2-3%.

Results of a conditional determination of residual resistance ($\rho_0 = \rho - \rho_t$), which to a certain degree characterizes electron scattering due to the absence of far order in the li-

---

G. V. Plekhanov Leningrad Mining Institute. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 29, No. 2, pp. 322-325, August, 1975. Original article submitted June 6, 1974.

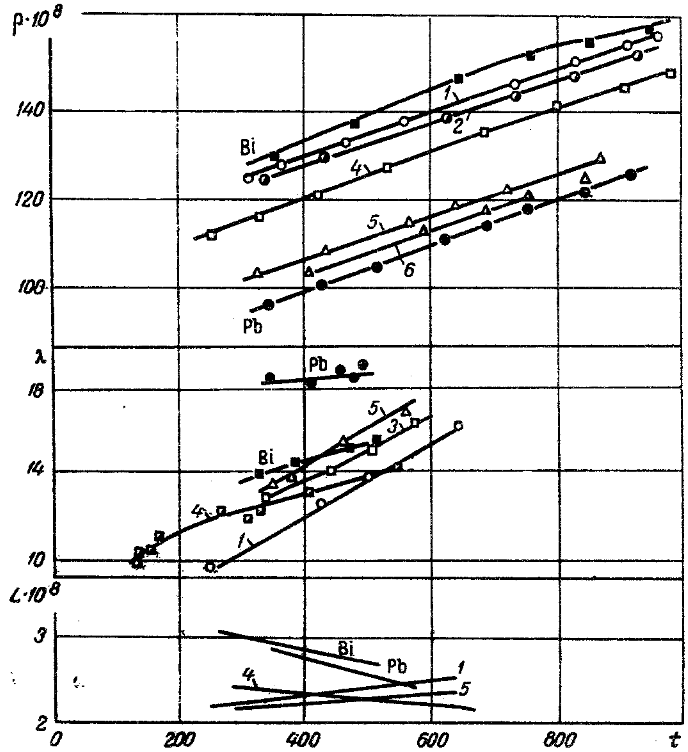

Fig. 1. Thermal conductivity, electrical resistance, and experimental Lorentz number versus temperature: 1) 88.93 Bi — 11.06 Pb; 2) 83.63 Bi — 16.22 Pb; 3) 70 Bi — 30 Pb; 4) 54 Bi — 45.9 Pb; 5) 22.85 Bi — 77.22 Pb; 6) 10.44 Bi — 89.56 Pb; $\rho\cdot10^8$, Ω·m; λ, W/m·deg; $L\cdot10^8$, V^2/deg^2; t, °C.

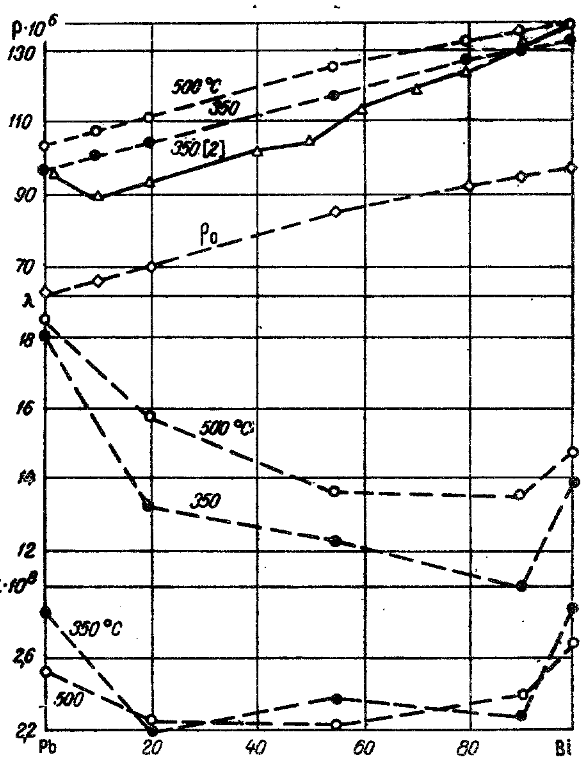

Fig. 2. Thermal conductivity, electrical resistance, and experimental Lorentz number versus alloy composition (wt. %).

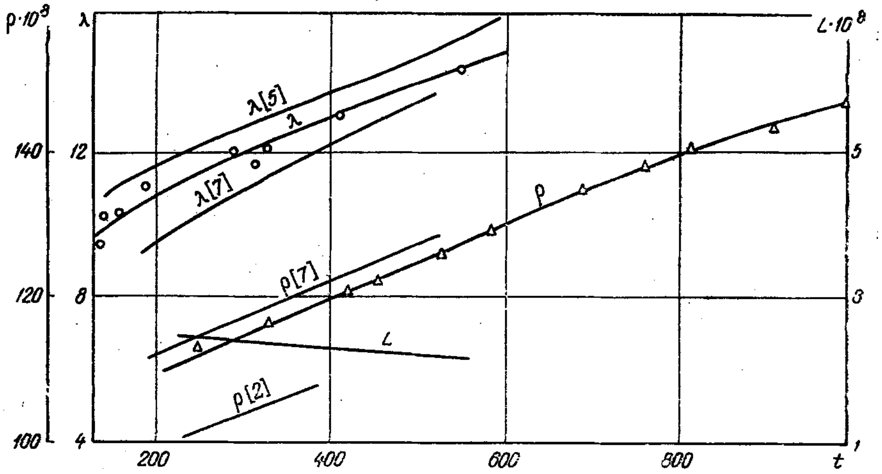

Fig. 3. Thermal conductivity, electrical resistance, and experimental Lorentz number versus temperature for eutectic lead–bismuth.

quid, are presented in Fig. 2.

The dependence of residual resistance on composition is of the same character as at temperatures of 350-500°C.

In our opinion, the electrical resistance–composition isotherms should have a smooth character, as is supported by the experiments performed, since no significant changes in structure of the alloys in the fused state were observed. Measurements of another structure-sensitive property, viscosity, performed by Sauerwald and coworkers [5] also indicated the absence of structural changes in lead–bismuth alloys. Viscosity–composition isotherms have a smooth character in the temperature interval 330-800°C.

For practical purposes the eutectic concentration alloy is of greatest interest. A large number of studies have been dedicated to the lead–bismuth eutectic [4, 6-9]. Figure 3 presents thermal conductivity and electrical resistance values for eutectic lead–bismuth, obtained in various studies.

The agreement of the electrical resistance results cannot be considered good, although the differences may be explained by some deviations from eutectic composition. The spread of the thermal-conductivity values for the eutectic alloy does not exceed the normal experimental error. The Lorentz number for lead and bismuth has a negative temperature coefficient. This is the normal case for pure liquid metals.

It should be noted that the experimental Lorentz numbers obtained for the binary alloys are not trivial, since the absolute value of the Lorentz number lies somewhat below the theoretical value for a degenerate electron gas. A qualitative evaluation of the possibility of existence of Lorentz number values below the theoretical is presented in [10].

NOTATION

λ, thermal-conductivity coefficient; ρ, resistivity coefficient; ρ_0, residual resistance; ρ_t, temperature-dependent resistance component; L, Lorentz number.

LITERATURE CITED

1. R. E. Krzhizhanovskii and N. P. Sidorova, Inzh.-Fiz. Zh., 7, No. 8 (1964).
2. R. E. Krzhizhanovskii, N. P. Sidorova, and I. A. Bogdanova, Inzh.-Fiz. Zh., 24, No. 1 (1974).
3. R. E. Krzhizhanovskii, N. P. Sidorova, and I. A. Bogdanova, in: Thermophysical Properties of Solids [in Russian], Naukova Dumka, Kiev (1971).
4. A. M. Korol'kov and D. P.Shashkov, The Study of Metals in the Liquid and Solid States [in Russian], Nauka (1964).
5. A. Bienias and F. Sauerwald, Z. Anorg. Chem., 161, 51 (1927).
6. N. A. Nikol'skii, N. A. Kalakutskaya, I. M. Pchelkin, T. V. Klassen, and V. A. Vel'tishcheva, Teploénergetika, No. 2 (1959).

7. Brown, Phys. Rev., 22, Nos. 1-2 (1923).
8. Liquid-Metals Handbook (1952).
9. A. R. Regel', Author's Abstract of Doctoral Dissertation, Leningrad State University (1956).
10. J. M. Ziman, Physics of Metals, Cambridge University Press (1969).