EXPERIMENTAL DETERMINATION OF THE HEAT CAPACITY OF LIQUID TIN AT HIGH TEMPERATURES

1965

SovietRxiv

Abstract

Full Text

PHYSICAL CHEMISTRY

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EXPERIMENTAL DETERMINATION OF THE HEAT CAPACITY OF LIQUID TIN AT HIGH TEMPERATURES

(Presented by Academician V. V. Voevodsky, 9 XI 1964)

There are no data in the literature on the heat capacity of molten metals at temperatures above 1000–1100°. This is due to the great difficulty of experiments with liquid metals at high temperatures. At the same time, knowledge of the properties of liquid metals at high temperatures, in particular their heat capacity, is of considerable theoretical and practical interest.

The present work describes a new method for determining the heat capacity of liquid metals at high temperatures and the results of measurements of the heat capacity of tin at temperatures from 900 to 1700°.

The essence of the method is as follows (Fig. 1). The liquid metal under study is placed in a thin-walled ampoule of small diameter (in our experiments the ampoules were made from a niobium capillary and had internal and external diameters, respectively, of 0.155 and 0.28, and 0.285 and 0.485 mm, and a length of about 60–80 mm). The ampoule filled with the metal under study, and an empty ampoule entirely analogous to it in dimensions, are fixed on independent holders inside a glass bulb, in which a vacuum of the order of $3 \cdot 10^{-6}$ mm Hg is produced. The holders are provided with current leads.

When an alternating electric current $i_0 \cos \omega t$ is passed, the ampoule is heated to a high temperature, periodically oscillating about a certain value. The current frequency is chosen so low that the temperature of the walls of the ampoule and of the molten metal filling it is practically one and the same; in our experiments ω was equal to 18 hertz. The amplitude of the temperature oscillations is determined from the change in luminosity of the outer surface of the ampoule by means of a photoelectric multiplier; the temperature of the ampoule is determined by means of an optical pyrometer.

From the basic equations, namely: the heat-balance equation of the ampoule

$$MC\frac{d\theta}{dt} + K\theta = \frac{i_0^2 R}{2}\cos 2\omega t, \qquad (1)$$

the equation for the current in the circuit of the photoelectric photomultiplier (caused by the thermal radiation of the outer surface of the ampoule):

$$i = be^{-a/T}, \tag{2}$$

the equation for the amplitude of the alternating component of the current in the circuit of the photoelectric multiplier (arising as a result of oscillations of the ampoule temperature):

$$i^1 = ai\frac{\theta_0}{T^2}, \tag{3}$$

the equation for the alternating component of the voltage drop across the resistance R_ϕ of the photoelectric-multiplier circuit (measured with a tube voltmeter):

$$V = i^1 R_\phi \tag{4}$$

it follows that, at a high temperature of the ampoule in its small diameter, when $\frac{K}{MC} \ll 1$, and at one and the same current in the circuit of the photomultiplier, in the case of an empty and a filled ampoule:

$$\theta = \theta_0 \sin 2\omega t; \qquad \theta_0 = \frac{W}{2MC\omega}; \tag{5}$$

$$c = \left(\frac{W}{W_\text{n}}\frac{V_\text{n}}{V} - 1\right)\frac{m_\text{n}}{m}c_\text{n}. \tag{6}$$

Here M and C are the mass and heat capacity of the ampoule (for the filled ampoule MC is equal to $m_\text{n}c_\text{n} + mc$, where m_n and c_n are the mass and heat capacity of the material from which the ampoule is made, i.e., niobium, and m and c are the mass and heat capacity of the liquid metal under study; in what follows all quantities referring to the empty ampoule are denoted by the subscript "n"); θ is the deviation of the ampoule temperature from its equilibrium value T; $K\theta$ is the increase in heat transfer from the ampoule, caused by the rise of the ampoule temperature from T to $T + \theta$; i_0 is the amplitude of the alternating current of frequency ω passed through the ampoule; R is the resistance of the ampoule at temperature T (in this case the electric power released in the ampoule is $W = \frac{i_0^2 R}{2}$); a and b are constants that depend on the experimental conditions (in the case of monochromatic radiation $a = \frac{h\nu}{\chi}$). The constancy of i is achieved by stopping down the collecting lens, located between the photomultiplier and the bulb, in the same way for both ampoules.

Fig. 1. Schematic diagram of the experimental setup

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Fig. 2. Dependence of the heat capacity (volumetric) of liquid tin on temperature

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Expressing in equation (6) m_{n} and m through the outer and inner diameters of the ampoule D and d and the specific weights of niobium and of the metal under study, γ_{n} and γ, and taking into account that the product $c\gamma$ represents the heat capacity of a unit volume c', we obtain:

$$c' = \left(\frac{W}{W_{\text{n}}}\frac{V_{\text{n}}}{V} - 1\right)\left(\frac{D^2}{d^2} - 1\right)\gamma_{\text{n}} c_{\text{n}}. \tag{7}$$

Formula (7) makes it possible, from the values W, W_{n}, V, V_{n} measured in the experiment (under the conditions: $T = T_{\text{n}}$ and $i = \text{const}$) and the known values of γ_{n} and c_{n}, to determine the volumetric heat capacity of the liquid metal under study. To eliminate end effects, it is advisable to measure the power on a small internal section of the ampoule with the aid of potential leads.

The method described is a variant of the modulation method for determining heat capacity, which has recently been successfully used to measure the heat capacity of solids ([1,2]); for measuring the heat capacity of liquid metals, the modulation method has been applied in the present work for the first time. The error in measuring the heat capacity of liquid metals by this method at high temperatures is no more than 5-7%.

Below and in Fig. 2 are the values we obtained for the volumetric heat capacity of liquid tin in the temperature range from 900 to 1700°. In the calculation we used the values of the heat capacity of niobium obtained in work ([3]), as well as the dependence of the coefficient of linear expansion of niobium on temperature given in work ([4]).

t, °C	895	950	1140	1245	1400	1510	1600	1700
c', J/cm^3·deg	2.01	1.85	1.78	1.72	1.61	1.52	1.44	1.42

It can be seen from Fig. 2 that the volumetric heat capacity of tin decreases somewhat—on the whole, only slightly—with increasing temperature.

It is appropriate to note that the values of the heat capacity of tin obtained in the present work at temperatures of 930 and 1100° agree satisfactorily with those available in the literature ([5,6]) (in Fig. 2 the latter are marked by squares).

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Received
9 X 1964

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Note: Figure translations are in progress. See original paper for figures.