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THE STUDY OF THERMAL PROPERTIES OF LIQUID METALS USING THE METHOD OF TEMPERATURE RADIAL WAVES

Băncilă Simion – doctor
(Alecu Russo Balti State University, Republic of Moldova)

The study of thermal properties of liquid metals and namely of fusion, conductivity and thermal capacity is motivated. The article describes the installation for experimental study of thermal characteristics of liquid metals for the temperature interval of 1000-2500k using the method of temperature radial waves. Heating of the investigated samples is carried out in vacuum by electron bombardment of their surfaces. Power modulation in the form of Π is applied. The article describes two variants of application of the method of temperature radial waves: by heating the interior surface of the sample and by heating the exterior surface. The results of the investigation of the molar capacity of liquid metals, such as In, Ga, Tl are presented.

INTRODUCTION

The paper represents one of the stages of experimental research of substance liquid state carried out by the Department of Molecular Physics of the Faculty of Physics of M. V. Lomonosov State University of Moscow and by the Department of Physics and Methods of Teaching Physics of Alecu Russo State University of Bălți [1, 2]. These investigations aim at finding out the nature of heat movement in liquids. The study of substances thermal properties such as heat conductibility, temperature conductibility, and thermal capacity, i.e. of such properties the quantity of which is considerably determined by heat movement, is important for the solution of this problem.

One of the important tasks here is the investigation of the specific character of manifestation of heat movement in liquid metals, elucidation of the influence of a metal electrons on thermo-dynamic properties, the study of their role in transfer processes. The investigation of thermal properties of liquid metals is important for modern technics in connection with more and more widely use of liquid metals in nuclear energetics, rocket-powered technics, MHD energetics, and metallurgy.

The following problems can be singled out in the investigation of thermal properties of liquid metals:

1. Investigation of thermal capacity of liquid metals in a wide range of states, subsequent comparison of this with specific heat of monoatomic non-metallic substances as well as revealing specific properties of liquid metals. These particularities can serve as an instrument to elucidate the problem of liquid metal elections participation in thermal movement, but can also be applied to analyze the influence of interparticle interaction specificity in metal baths.
2. The investigation of heat capacity in the area of temperatures and pressures where transition from metallic to dielectric properties takes place is of specific interest. The problem concerning the area and nature of this transition remains for the time being open. Heat capacity behaviour in the area of states where abrupt qualitative changes of metal bath nature take place can probably give us information about the character of this transformation.
3. Investigations into heat and electric conductibility and analysis of the Lorentz number behaviour are important in order to elucidate the problem about the role of conductivity electrons in the process of heat transfer in liquid metals.

Primary role in the investigation of the enumerated problems should belong to experimental study. The theory of liquid state hasn't been created yet, and effective methods of quantitative description of the properties of liquids haven't been elaborated. Little is clear in the problem about the nature of heat movement in liquids. The above said refers to metal liquids as well, where to difficulties that are characteristic for liquids as such are added complications inherent in electronic theory.

Considerable progress in the investigation of thermal properties of liquid metals was achieved at the Department of Molecular Physics of the Faculty of Physics of Moscow State University. Here, they elaborated more investigation methods that are distinguished by their complex character, i. e. by the possibility of obtaining in an experiment of a multitude of basic thermal characteristics: thermal capacity, temperature conductibility, thermal conduction. One of these methods, the method of radial temperature waves, was used for systematic investigation of the properties of liquid metals in a wide temperature range. This method was used to investigate thermal properties of some liquid metals such as: praseodymium, dysprosium, lanthanum, gallium, thallium, indium, tin and lead [2, 3, 4]. The choice of rare metals as objects of study is explained by their specific characteristics: relatively active participation of electrons of inner shell in thermal movement, which is reflected in an anomaly of high heat capacity and anomaly of little changes in heat and electricity conduction in the process of melting, which can probably be explained by the role of inner shell electrons. Investigations conducted by the author of the present study add to the knowledge of this important field for a number of rare metals.

The study of thermal properties of fusible metals aimed to investigate the variations of studied characteristics in as large a range of temperatures as possible and to compare thermal and electrical conduction. The results obtained during these investigations for tin and lead disagree with the previous results. In this connexion, a supplementary and deeper study of methodology became necessary. One of the problems, and mainly, complete control of the quality of filling with metal of the work cell of measurement device, was solved by using γ flow detector [2]. In order to study another problem, the possible influence of convective transfer, the author elaborated a new method of measurement, and namely, the method of external heating of the hollow sample with electron bombardment by contrast with the previously used methods of internal heating [2, 5]. This required essential modification of the whole working part of the experimental installation and elaboration of a new methodology theory.

The conducted investigation allowed to ascertain that the new data received by the author is quite trustworthy and the question of revision of one of the conclusions from previous works should be raised, the conclusion concerning the existence of noticeable negative deviations from Wiedemann-Franz Law .

RESULTS OF EXPERIMENTS

Lately, new methods of determining thermal characteristics (thermal conduction, fusion and heat capacity) based on the use of periodic heating have been elaborated [3]. Advantages of these methods include continuous reproduction of data, possibility of internal control of the results, small correction under the influence of heat transfer, etc. Methods of periodical heating are of several variants, distinct by the configuration of the temperature field and the form of periodic sign. In an overwhelming number of variants, modulation of power in Π form is applied [5]. As a rule this modulation is simpler in execution than harmonic modulation, which requires application of some difficult methods of harmonic analysis for the results processing.

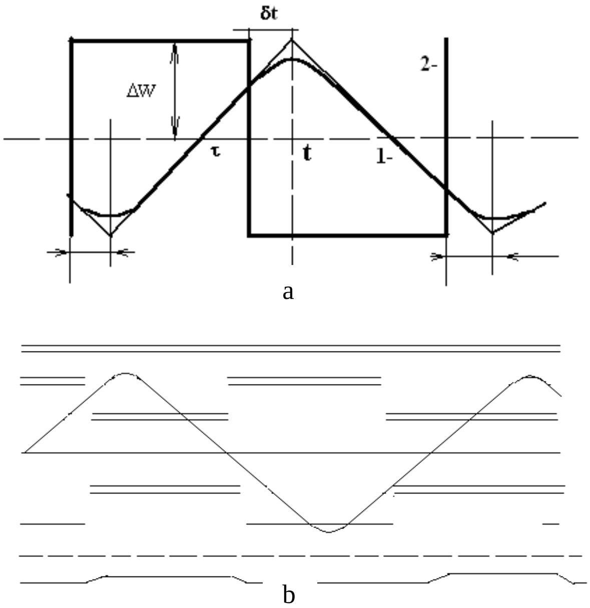
The essence of the method consists in the following. The investigated sample presents a tubular cylinder or a cell filled with liquid metal and is made of two coaxial tubes. The surface of the cavity is periodically warmed up by electron bombardment. Variations of temperature produced on the opposite surface are registered either by photoelectric method or with the help of a thermocouple. Thermal diffusivity of a system with known geometry is determined depending on the character of travel of periodical curbs of warming up power variation and on temperature variation. At calculating specific warmth, information about the same curbs of temperature and power variation is used.

In both variants the investigated sample presents a hollow cylindrical vessel filled with liquid metal. The vessel is made of two thin-walled tantalum tubes, with wall thickness of 0.1 mm, interior diameter of 6 mm, exterior cell of 14 mm, and length of (70…80) mm. The bottom and the cover of the sample are made of tantalum plates (1…2) mm thick, which are later welded to the sample by means of electron-ray welding. In order to diminish the possibility of convection appearance, 0.1 mm thick tantalum lamellas were mounted as separating walls in the sample at the distance of (5…10) mm. Vacuum rooms in which samples are assembled, represent brass covers with double walls cooled with water. The rooms are assembled on a BA-0,5-A type unit with the help of vacuum sets and props made of stainless steel and which contain orifices for electrons, and one of them (in the case with exterior variant) has an observation window.

During measurement, the vacuum in the working space is maintained at (10^{-5} …10^{-6}) Torr. The walls of the rooms have observation windows. One window is placed in the frontal wall (in the case with interior heating) and two windows are placed in the lateral wall (in the case with interior heating). The window are used to register temperature pulsations and to measure average temperature.

In the case of interior heating, the cathode represents a tungsten (0.4…0.8) mm diameter wire, which is installed on the sample axis. In the case of exterior heating, the cathode represents twelve tungsten 0.15 mm- diameter wires placed uniformly around the sample at a distance of 4 mm from it. Between the cathode and the sample, tension in the Π form is applied from a modulation electronic circuit. Constant fluctuation of the sample temperature is registered by fluctuations of luminousness of the sample surface (close to its centre), which are then oriented towards a photoelectronic (ФЭУ- 29 type) multiplier. At ФЭУ- 29 device output, the constant component, which corresponds to the average temperature of the sample, is compensated by reverse polarity tension introduced through compensation circuit. The variable component is amplified by a direct current amplifier, whose current amplifying factor constitutes 10^3 … 10^5, after which it is registered by an oscillograph on photo-sensible paper. Simultaneously, the tension and the current intensity variation curves are registered on the same paper. Interpretation of experimental results obtained through the method of periodic heating in Π form is based on the fact that temperature variation curves, which serve as sources of information about the thermic properties of the medium, have, in most cases, a clearly marked linear sector. For example, figure represents measurement curves of the temperature on the exterior surface of a tubular metallic cylinder, whose interior surface is heated by bombardment with electrons directed by the Π form sign.

The presence of a sector with linear heating (cooling) means that, within the limits of one semiperiod of the process, the so-called regular (steady) regime of the second kind manages to settle in the sample [1].



b

Fig. Temperature oscillations curves:
a) theoretical, b) experimental.

Invariableness of the speed of temperature variation of all the sample points is characteristic for this regime. Examination of this phase of the process can give complex information about thermal characteristics of the investigated materials. The work [2] demonstrates that the inclination angle of linear sector of temperature variation curve, that is, the heating speed, makes it possible to determine specific heat in these experiments. The reciprocal position of heating and cooling lines allows to determine thermal capacity. The value of thermal capacity is determined univocally by the δt segment on the oscillogram, similar to the one in figure.

Thermal diffusivity and capacity are

calculated using the correlations:

$$a = \frac{R_2^2}{8\delta t}\left[1+\xi^2+\frac{4\xi^2}{1-\xi^2}\ln\xi\right],$$

$$C_P = \frac{W}{2M\,\frac{dT}{d\tau}},$$

where R_1 and R_2 are interior and exterior beams of the sample;

$\xi = \frac{R_1}{R_2}$ is the beams correlation;

δt - quality of relative movement in time of the variation of heating power with regard to temperature oscillation of the sample surface;
W - quantity of heating power variation;
M - the sample mass;
$\frac{dT}{d\tau}$ - heating speed.

The results of measurements of molar thermal capacity of studied metals (C_p, $\frac{cal}{molK}$) are given in table.

The results of measurements of molar thermal capacity

T,K / Metal	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100
In	6.95	6.87	6.79	6.71	6.63	6.55	6.47	6.39	6.31	6.23	6.15
Ga	6.27	6.28	6.30	6.31	6.32	6.33	-	-	-	-	-
Sn	6.56	6.52	6.48	6.44	6.41	6.37	6.33	6.29	6.25	6.22	6.18

The relative error at determining thermal capacity constituted about 3…5 %.

The compositions of studied metals, expressed in weight percentage, are the following: 99.995 Sn;5 10^{-5} Sb; 10^{-5} (Fe, Ga, Au, Zn, Ar); 10^{-6} (Cu, Bi, Al).
In- Fe $\prec 10^{-5}$; Cu 4 10^{-6}; Ni 2 10^{-5}; Pb 10^{-5}; Sn 10^{-4}; Zn 2 10^{-5}; Tl 10^{-5}; Ga 99.997.

Easily fusible metals are characterized by monotonous diminution of thermal capacity at constant pressure with temperature. By such behaviour liquid metals differ from nonmetallic monatomic substances, such as liquid inert gases. With the latter, C_p grows monotonously with temperature. The difference between the behaviour of nonmetallic and metallic substances proves the essential influence of the type of molecular interaction on thermodynamic properties of substances, the specific character of metallic bounds manifestations.

The dependence on temperature of samples electric conductivity was investigated by the author earlier using potentiometer method [2]. On the basis of accumulated experimental results Lorentz number was calculated.

Carried out experiments confirm validity of Wiedermann-Frantz law for all the studied metals in an interval of temperature variation about 1600 K higher than their melting point.

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STUDIUL PROPRIETĂȚILOR TERMICE ALE METALELOR LICHIDE PRIN METODA UNDELOR RADIALE DE TEMPERATURĂ

Băncilă Simion – dr., conf.
(Universitatea de Stat „Alecu Russo” din Bălți, Republica Moldova)

În articol se descrie instalaţa destinată studiului experimental al proprietăților termice ale metalelor lichide (difuzivitatea, conductibilitatea şi capacitatea termică) prin metoda undelor radiale de temperatură (1000 ÷2500 K). Încălzirea probelor de cercetare are loc în vid în rezultatul bombardării lor cu electroni. S-a practicat modularea puterii în forma de *П.* Sînt prezentate două variante de aplicare a metodei sus numite prin încălzirea suprafeţei interioare a probei şi prin încălzirea suprafeţei ei exterioare. Sunt prezentate rezultatele dependenței capacităților molare de temperatură a metalelor lichide *In,Ga,Tl*.

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