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SPECIAL SHAPE OF SAMPLES FOR THERMOPHYSICAL MEASUREMENTS

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There are shown in this paper some simple arrangements of samples suitable for the realization of thermophysical measurements and for a simple calculation of thermophysical quantities. Two of these arrangements were tested. The obtained results are in good agreement with the published data.

СПЕЦИАЛЬНАЯ ФОРМА ОБРАЗЦОВ ДЛЯ ТЕРМОФИЗИЧЕСКИХ ИЗМЕРЕНИЙ

В работе описано несколько простых форм и расположений образцов, предназначенных для термофизических измерений и простого вычисления термофизических величин. Два из этих расположений проверены в действии. Полученные результаты находятся в хорошем согласии с опубликованными данными.

I. INTRODUCTION

From the theoretical and also practical point of view the following parameters are of great importance: thermal conductivity (λ), thermal diffusivity (k), specific heat (c), Lorentz number ($L = \lambda / T\sigma$), Seebeck coefficient (α) and thermoelectric efficiency ($z = \alpha^2\sigma/\lambda, \sigma$ being electrical conductivity). All measurements of these paremeters require a heat source which produces the temperature gradient in the samples. With the exception of the Seebeck coefficient the measurements of all the parameters mentioned above also require the value of the magnitude of heat produced in the sample to be known. Especially this fact causes great difficulties and an insufficient precision as regards thermophysical measurements. We do not know the perfect thermal conductors, not even perfect thermal insulators, therefore it is practically impossible to calculate the quantum of heat which the sample

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receives from the heat source. It seems that there exists a solution of this difficult problem: to realize the heat source in the sample itself — using the Joule effect. This method can be used of course only for the measurement of non-insulators.

We shall show in this paper some simple arrangements of samples suitable for the realization of thermophysical measurements and for a simple calculation of thermophysical quantities.

II. THIN PLATES AND THIN FILMS

Let us consider samples of the type of a thin plate or a thin film. (Fig. 1). The sample is semi-infinite, its thickness is very small (in relation to the distance l). The heat source is realized by the current flowing between the condustors 1 and 2 (two blades). The electrical conductivity of the sample is supposed to be so low that the current flows practically in the region between these conductors only.

The element of the sample S dx (S being the cross section and dx its thickness) produces the heat

$$dQ = I^2 dR \Delta t = I^2 \varrho \frac{dx}{S} \Delta t \,, \tag{1}$$

where ϱ is specific resistivity and Δt the interval of time. According to [1] this heat causes a temperature increase at the point X (where a thermocouple is located)

$$dT = \frac{\varrho I^2 \sqrt{k \Delta t}}{2\lambda \sqrt{\pi t}} \exp\left[-\frac{x^2}{4kt}\right] dx \,. \tag{2}$$

The temperature increase due to the whole source of the length l is therefore

$$\Delta T = \int_{x_1}^{x_2} dT \frac{\varrho I^2 \sqrt{k \Delta t}}{2\lambda \sqrt{\pi t}} \int_{x_1}^{x_2} \exp\left[-\frac{x^2}{4kt}\right] dx = \tag{3}$$
$$= \frac{\varrho I^2 \Delta t k}{2\lambda} \left\{\Phi\left[\frac{x_2}{2\sqrt{kt}}\right] - \Phi\left[\frac{x_1}{2\sqrt{kt}}\right]\right\}$$

where $\Phi(z) = \frac{2}{\sqrt{\pi}} \int_0^z e^{-Y^2} dy$.

If the heat source acts only for a short time (the pulse method), we can calculate the thermophysical quantities in terms of the measured values of the time (t_m) in which the temperature at the place of the thermocouple reaches its maximum value and of

the value of this maximum (ΔT_m). The condition for the maximum ($dT/dt = 0$) gives the result

$$k = \frac{x_2^2 - x_1^2}{4 \ln \frac{x_2}{x_1}} \frac{1}{t_m} = A^2 \frac{1}{t_m} \,, \tag{4}$$

where A is a constant.

This relation offers a very simple formula for the calculation of the thermal diffusivity. Knowing this value we can know also the Φ functions in the relation (3) and if the value ΔT_m is also known, we can calculate from the relation (3) the thermal conductivity λ and the specific heat c (using the relation $k = \lambda / c\gamma$, where γ is the specific (mass).

Now we shall show how the relation (3) can be used for the direct measurement of the Lorentz number L. Expressing the current I by the relation

$$I = \frac{U}{R} = \frac{U}{\varrho l} S$$

and using the substitution, we obtain the relation

$$\frac{\lambda}{\sigma T} = B \frac{1}{T \Delta T_m t_m} \tag{5}$$

where $B = \frac{U^2 S^2 \Delta t}{2 l^2} \frac{x_2^2 - x_1^2}{4 \ln \frac{x_2}{x_1}} \left\{\Phi\left[\frac{x_2}{2A}\right] - \Phi\left[\frac{x_1}{2A}\right]\right\}$ is another constant. If the thermal conductivity of the sample is defined predominatly by the free charge carriers, the relation (5) has the meaning of the Lorentz number.

III. BULK SAMPLES

The arrangement discussed above is not applicable to the bulk materials because of the current flowing through the whole sample. In this case we can use the sample with non equal crosssections. (Figs. 2a, 2b, 2c). The first or second can be easily realized when material made in the form of thin plates has to be mesured. It is possible to cut the large plates into small pieces and make a sample of the shape 2a or 2b, respectively. All the types of the samples (2a, 2b, 2c) are suitable for direct measurements of the Seebeck coefficient, because the temperature gradient arises automatically if the a.c. current flows through. For measurements of the other parameters it is necessary to claculate the quantum of heat generated in the medium region.

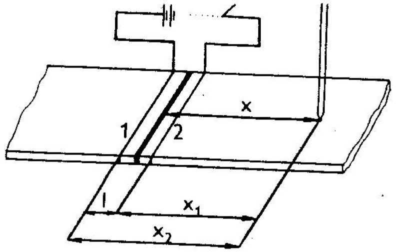

Fig. 1. The arrangement for measuring thermophysical parameters of thin plates by the pulse method.

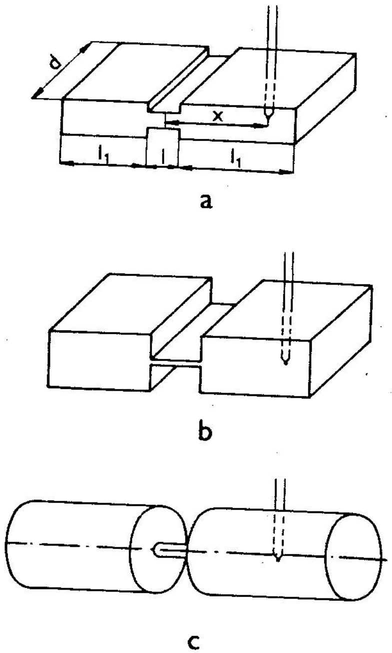

Fig. 2a, 2b, 2c. Special shapes of samples for thermophysical measurements.

Let us suppose the cross sections of the sample S_1, S and its lengths l_1 and l. The heat generated in regions in 1s is

$$Q_1 = RI^2 = \varrho \frac{l_1}{S_1} I^2 , \qquad (6)$$

resp.

$$Q = RI^2 = \varrho \frac{l}{S} I^2 . \qquad (7)$$

Due to the heat Q_1 the increase of temperature ΔT_1 is

$$\Delta T_1 = \frac{Q_1}{c\gamma S_1 l_1} = \frac{\varrho I^2}{c\gamma} \frac{1}{S_1^2} . \qquad (8)$$

The heat generated in the medium region can be divided into two parts: the first (Q') causes the same increase of temperature as the heat Q_1 in the regions with larger cross sections — (the sample has the same temperature $T = T_0 + \Delta T_1$) and the rest $Q'' = Q - Q'$ which acts as the heat source for the measurement. It is easy to derive the following formula for the power of this source.

$$Q'' = Q - Q' = Q - c\gamma S l \Delta T_1 = \varrho I^2 \frac{1}{S} \left\{ 1 - \frac{S^2}{S_1^2} \right\} . \qquad (9)$$

It should be difficult to calculate the temperature distribution in the samples due to heat generated from the power (9) in general. It is possible, however, to realize the sample with parameters $l \ll x$. In this case the heat source 2a acts as a plane source, the heat source 2b as a linear source and the heat source 2c as a point source. Because of the transport of the heat in two directions we must calculate with the energy $Q = Q''/2$. According to [1] the thermal diffusivity and the thermal conductivity are expressed by the relations:

$$k = \frac{x^2}{2t_m} \qquad \lambda = 0.121 \frac{Q^* x \Delta t}{S \Delta T_m t_m}$$

$$k = \frac{x^2}{4t_m} \qquad \lambda = 2.93 \times 10^{-2} \frac{Q^* \Delta t}{x \Delta T_m t_m}$$

$$k = \frac{x^2}{6t_m} \qquad \lambda = 2.44 \times 10^{-2} \frac{Q^* \Delta t}{x \Delta T_m t_m}$$

Using the transformation

$$I = \frac{U}{R} = \frac{U}{\varrho \left[\frac{2l_1}{S_1} + \frac{l}{S} \right]}$$

where U is the voltage, we can obtain for the ratio $\lambda / T\sigma$ the relation (5) with some different values of the constant B. In the case of a predominant electronic mechanism of the transport of the heat it is easy to measure the Lorentz number. We used this method for measuring the Lorentz number of a morphous metal alloys.

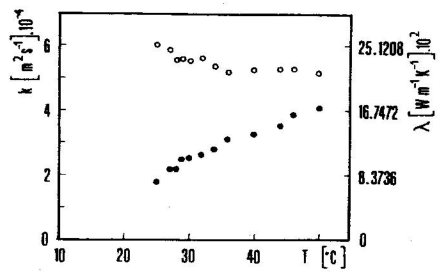

Fig. 3. Temperature dependence of thermal conductivity and thermal diffusivity measured by the arrangement in Fig. 1. The empty rings correspond to the thermal diffusivity — k. The full rings correspond to thermal conductivity — λ.

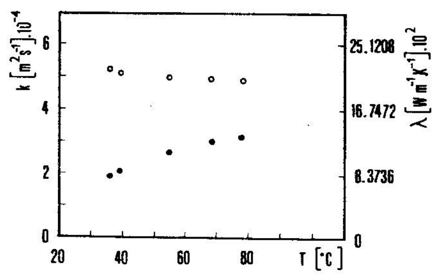

Fig. 4. Temeperature dependence of thermal conductivity and thermal difusivity measured by the arrangement in Fig. 2c. The empty rings correspond to thermal diffusivity — k, the full rings correspond to thermal concuctivity — λ.

IV. EXPERIMENTAL

Bismuth was selected as study material because of its relatively low electric conductivity. The arrangements outlined in Fig. 1 and Fig. 2c were tested. The thickness of the bismuth plate in Fig. 1 is 0.3 mm and the electric pulses were applied to the sample by two blades. The arrangement by Fig. 2c was realized as follows: the quartz tube with a diameter of about 7 mm has in the middle a partition with a hole in it. The diameter of the hole is 0.2 mm and the thickness of partition is 1 mm. The quartz tube was fulfilled with melted bismuth which immediately stiffened and created the desired form. The electric pulses were applied to the sample by conductive contats sealed to the edges of the sample. Ni-NiCr thormocouples were used in both arrangements.

The thermal dependence of thermal conductivity λ and thermal diffusivity k have been measured. The values of these parameters are plotted in the graphs. To compare the measurements by two distinguishable arrangements one can see that the proposed measuring method is correct in principle and it is convenient mainly for such measurements where the influences of external parameters on thermal characteristics are studied, e.g. in cases where absolute values of parameters are not required.

V. CONCLUSION

It was shown theoretically and also practically that complications with the thermal source in thermal measurements can be avoided using samples of special shapes in which the heat is generated on the basis of the Joule effect. Formulas suitable for calculating thermophysical quantities were found. The advantages of this method of measurement are that no external heat source is necessary and therefore no trouble with the thermal contact arises. This arrangement is very convenient when the temperature dependence of thermophysical quantities is measured in large intervals of temperature and the dependence on other factors, e.g. the electric and the magnetic field, the mechanical stresses, etc. is studied.

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