A METHOD OF MEASURING THE SPECIFIC HEAT OF METALS BY RAPID HEATING

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Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, Vol. 8, No. 4, pp. 141-143, 1967

The majority of existing methods of measuring the specific heat at high temperatures require that the material being investigated be held at elevated temperatures for a comparatively long period. Hence difficulties arise in the study of materials whose properties may undergo change with time (recrystallization, allotropic changes, etc.) by existing methods other than impulse methods [1]. A description is given below of a method of measuring the specific heat of metals by heating them rapidly over a wide temperature range, so that the metal under investigation is at high temperature for only a comparatively short time. The specimen, in the form of a fine wire in a vacuum, is heated by passing an electric current through it. The heat liberated goes into heating the wire, and there is some loss by thermal conduction through the ends and by radiation from the surface. With increase in the rate of heating, the proportion of the heat lost from the surface and through the ends diminishes in comparison with the amount that goes into heating the wire.

A theoretical evaluation of the method shows that the heat losses can in practice be neglected over the whole range of heating from room temperature to 1500° C if a wire about 200 mm long is heated at a rate on the order of tens of thousands of degrees per second. In this case all of the heat liberated goes into heating the specimen, and the specific heat may be determined from the formula

$$c_p = \frac{Q}{m dT / d\tau}. \qquad (1)$$

Here Q is the thermal energy liberated in the wire, m is the mass of wire, and T is the temperature.

By measuring the temperature variation with the time and also the thermal energy Q and calculating $dT/d\tau$, it is possible to determine the specific heat.

For this purpose the experimental setup shown diagrammatically in Fig. 1 was used; here 1 is the specimen, 2 is a time relay, 3 is an amplifier, 4 is a Schmitt trigger, 5 is a time-measuring device 6 is a potentiometer, 7 is a rapid-action switch, and 8 and 9 are two-way switches.

The filament 1 being investigated, with the resistance R joined in series, is connected to a dc source by the rapid-action switch 7. As a result, the filament is heated up, its resistance increases, and consequently the potential drop at it varies with time. To measure the time dependence of this potential, one measures the time from the start of heating to the attainment of a definite potential level at the wire. By repeatedly heating the wire at various levels, the dependence can thus be determined. The level is set by an auxiliary circuit (source E_2, resistances R_1, R_2, R_N) and is equal to the potential drop at the resistance R_1. The potential difference at the filament being investigated and the resistance R_1 supplies the input to the threshold circuit consisting of the wide-band dc amplifier 3 and the Schmitt trigger 4. At the instant when the heating of the wire is begun by a pulse from the contact 7, the time-measuring device 5 is triggered.

The latter stops when the potential difference at the wire and the resistance R_1 is zero.

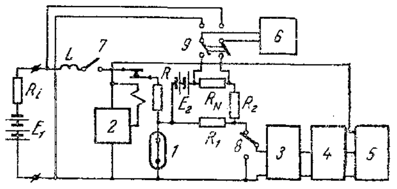

Fig. 1

The specific heat can be calculated from the measured time dependence of the potential at the wire. As can be seen from the diagram, the thermal energy liberated in the wire is

$$Q = U(E_1 - U) / R, \qquad (2)$$

where R also includes the internal resistance of the source R_i.

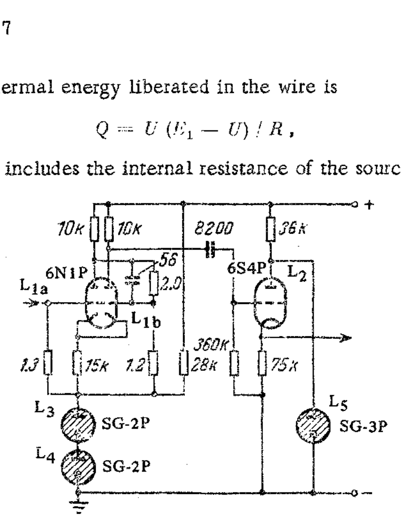

Fig. 2

The time dependence of the potential drop at the filament determines its rate of heating. The potential at the specimen is

$$U = ER_T / (R + R_T). \qquad (3)$$

In Eq. (3) E_1 and R are constants, while the resistance of the wire R_T depends on its temperature T, which in turn varies with the time τ, i.e. $U = U(R_T(T(\tau)))$. Differentiating U with respect to τ, we obtain

$$\frac{dU}{d\tau} = \frac{\partial U}{\partial R_T}\frac{dR_T}{dT}\frac{dT}{d\tau} =$$

$$= E_1\left\{\frac{1}{R + R_T} - \frac{R_T}{(R + R_T)^2}\right\}\frac{dR_T}{dT}\frac{dT}{d\tau} =$$

$$= \frac{E_1 R}{(R + R_T)^2}\frac{dR_T}{dT}\frac{dT}{d\tau}, \qquad (4)$$

whence the rate of temperature change is

$$\frac{dT}{d\tau} = \frac{dU}{d\tau}\frac{(R_T + R)^2}{ERR_0\alpha} \qquad \left(\alpha = \frac{1}{R_0}\frac{dR}{dT}\right). \qquad (5)$$

Here α is the temperature coefficient of resistance. By substituting Eqs. (2) and (5) in (1), we obtain the following formula for determining the specific heat:

$$c_p = \frac{R_0}{mE_1R^2}\frac{U(E - U)^3}{dU / d\tau}\alpha. \qquad (6)$$

A platinum wire, 0.05 mm in diameter and 180-200 mm long, welded to special contacts on the holder, was chosen for the specific-heat determination. After annealing to check the degree of purity of the metal, its resistance was measured at 0 and 100° C, and the wire was installed in a vacuum chamber. The dc source E_1 consisted of an accumulator battery of 115 volts and a 0.6-ohm internal resistance. The reactance-free R varied from 20-60 ohms in the experiments. In the rapid-action switch 7 one of the contacts consisted of a lead plate while the other was a copper rod with a pointed end. The switch completed the filament-heating circuit by the copper rod sharply striking the plate.

The resistances R_1 and R_2 are resistance boxes having a high degree of accuracy (0.02) and R_N is a standard resistance coil of 100 ohms. The potentials E_1 and U required in calculating the specific heat are measured by means of a dc potentiometer. The wide-band dc amplifier 3 is the vertical-deflection amplifier of the S1-19A oscillograph. The output from the amplifier is connected to the Schmitt trigger, whose circuit is shown in Fig. 2. The trigger activates when the potential on the grid of the tube L_1 increases until it becomes equal to the triggering threshold. A pulse is formed at the anode of the L_2 and this is fed to the grid of the cathode follower L_3. With the output from the latter the impulse is fed to the "stop" terminals of the time-measuring device 5 (Fig. 1), an F519 frequency meter with a resolving power of 1 μsec. To prevent the wire from becoming overheated, a time relay 2 is used which switches off the heat after a predetermined time.

The procedure for determining the specific heat is as follows: a definite potential level at R_1 is established by means of the resistances R_1 and R_2; the zero of the threshold circuit is fixed. For this purpose the amplifier input is short-circuited by the switch 8, and operation of the trigger is achieved by regulating the "balance" of the oscillograph. With a gain for the amplifier of about 1000, the variation in the triggering threshold does not exceed 0.5 mV. After the zero has been fixed, switch 8 is changed over to the operating position and switch 7 is closed. At that instant (the beginning of heating) the time-measuring device is triggered by a pulse from the contact 7. When the wire reaches a predetermined temperature, the threshold circuit operates to stop the timing device 5.

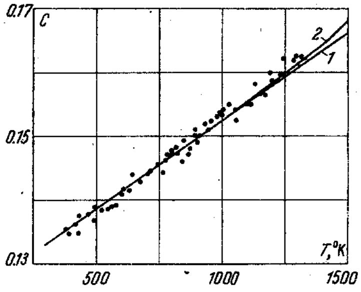

Fig. 3.

The readings of the timing device and the potentials U and E_1 are recorded in a table of measurements. After this, 2–3 minutes are required for the wire to cool to its initial temperature, and during this time a new level of U is established; then the zero of the threshold circuit is checked and the next measurement is taken and so on.

Differentiation of the potential/time function was carried out by the method of least squares.

In the experiments the rate of heating the specimens was varied by choosing different values of the resistance R from 6000 to 10^5 deg/sec. It was found that at heating rates less then 20 000 deg/sec the value calculated from Eq. (6) depends at high temperatures on the rate of heating; this is due to heat loss by heat conduction through the ends of the specimen. At higher rates of heating no dependence on the rate of heating was observed.

Measurements were made in the temperature range 400–1800° K, but owing to the absence of reliable data for α at the higher temperatures the specific heat was calculated only up to 1470° K.

The results of specific-heat measurements on platinum C in 10^3 J/kg deg in the range 400–1470° K, obtained at heating rates of 20 000 to 10^5 deg/sec, are given in Fig. 3, in which the points indicate our data (1 is from [2] and 2 is from [3]). A preliminary estimate shows that the error in measuring the specific heat is about 3%. Within the limits of accuracy of the method, the data obtained agree with those of other authors.

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