Practical 11

DETERMINATION OF SPECIFIC HEAT CAPACITY OF THE SOLID BODIES AT ROOM TEMPERATURE

Objective: Verification of the Dulong and Petit law for metals at room temperature.

***Instruments and accessories*:** calorimeter, rectifier type BCA-5K, ammeter, milliammeter, digital voltmeter, voltage stabilizer.

INTRODUCTION

In solid crystalline bodies, atoms or positively charged ions located at the sites of the crystal lattice make small oscillations around a certain equilibrium position with a frequency ν_0. Considering the vibrations of individual atoms to be independent of each other and assuming that $kT >> h\nu_0$, let's determine the heat capacity of the crystal.

Each atom can be considered as an oscillator with three oscillatory degrees of freedom. Under the above assumptions, one can apply the classical theorem on the equidistribution of kinetic energy over degrees of freedom. The average energy per one oscillatory degree of freedom is kT (k is the Boltzmann constant, T is the absolute temperature). Each atom has three vibrational degrees of freedom, and one mole of matter contains N_A (Avogadro number) atoms. Therefore, the internal energy of one mole of substance $U=3N_AkT$. Then the molar heat capacity at constant volume is equal to

$$C_V = \frac{dU}{dT} = 3N_A k = 3R,$$

where R is the molar gas constant. This relation is called the law of Dulong and Petit.

Experiments have shown that at high temperatures (of the order of room temperature and above), most solids follow this law quite well. However, in the low-temperature region, the heat capacity decreases with decreasing temperature, and $C \to 0$ at $T \to 0$, which can be explained only with the help of the laws of quantum mechanics.

The purpose of this work is to measure the heat capacity of solids at high temperatures. The methodology of the experiment is as follows. The investigated body is heated electrically in a calorimeter. First, the dependence of the temperature increment on time is determined for an empty calorimeter, then for a calorimeter with the test body. In this case, the current I_N in the winding of the heater spiral of the calorimeter is unchanged. In the absence of heat exchange with the environment, these dependencies would be linear. In real conditions, the plots of these dependencies have the form shown in Fig. 1.

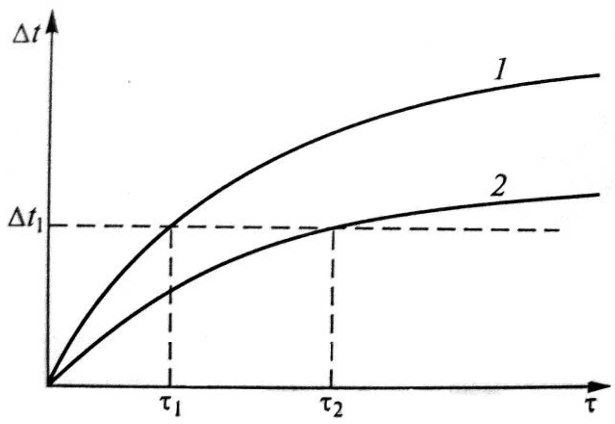

Fig. 1. Time dependence of the temperature increment

To heat an empty calorimeter by Δt degrees, a time period τ_1 is required, and to heat a calorimeter with a body by the same Δt degrees, a longer time period τ_2 is required. The specific heat of the test substance can be determined from the heat balance equation (the difference in heat loss to the surrounding space is neglected, which is not entirely correct, since the heating time is different):

$$I_H{}^2 R_H (\tau_2 - \tau_1) = cm\Delta t \, ,$$

from where

$$c = \frac{I_H{}^2 R_H (\tau_2 - \tau_1)}{m\Delta t} . \qquad (1)$$

Here c – specific heat capacity of the body, m – mass of the investigated body, R_N - resistance of the heater spiral, $\Delta\tau = \tau_2 - \tau_{1.}$

EXPERIMENTAL SETUP

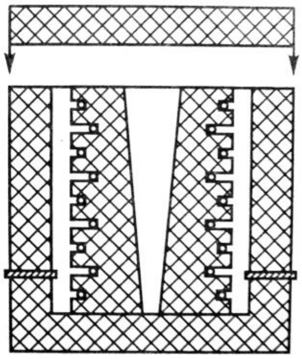

Fig.2. Calorimeter

To measure the heat capacity of metals, a calorimeter is used, the design of which is shown in Fig.2. The calorimeter is a brass body with a tapered bore, into which the bodies under investigation, having the shape of a truncated cone, are inserted. For copper body m=2.50 kg, for steel m= 2.17 kg. In the case of the calorimeter there is a heating spiral (stove) made of constantan and a spiral of resistive thermometer, made of copper wire. Outside the body of the calorimeter is closed by a heat insulating jacket. The bodies are placed in the calorimeter and removed from it only with the help of a special device.

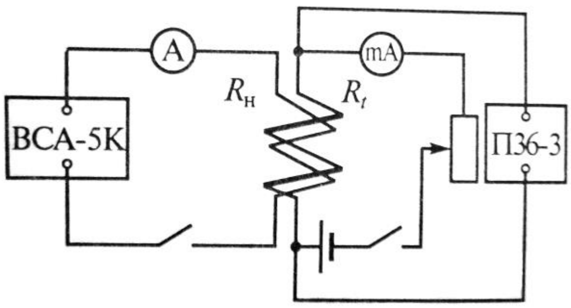

Fig. 3. Electric schematic of the experimental

The electric circuit of the calorimeter is presented in Fig. 3. Heater with resistance R_H= 100 Ohm is powered by a rectifier type BCA-5K. With the heating on, the temperature of the calorimeter increases over time. To measure the temperature, the dependence of the resistance of copper wire on temperature (resistance thermometer) is used. The voltage regulator П36-3 is used as a source of direct current in the measuring circuit of the thermal resistance. The resistance of thermometer spiral at different temperatures can be calculated on the basis of indications U_t of digital voltmeter and milliammeter "mA" included in the measuring circuit: $R_t = \dfrac{U_t}{I_t}$ (for convenience of calculations, the value of the current I_t in the measuring circuit is set to 1 mA).Knowing that the resistance of the metal varies with temperature according to the law: $R_t = R_0(1+\alpha \cdot t)$.

You can find the temperature t of the sample (here R_0= 2.967 Ohms- resistance of spiral of the thermometer at 0° C, R_t - resistance at temperature t, α =42,8$^{O}\cdot 10^{-4}$ K^{-1}- temperature coefficient of resistance of copper).

MEASUREMENT AND PROCESSING OF RESULTS

The electrical circuit is assembled in accordance with Fig. 3. In the Fig. 4. below the numbers indicate the individual elements of the setup.

Turn on voltage regulator *1* and digital voltmeter *2*. In this case, milliammeter 3 will show the current in the measuring circuit I_t= 1 mA. The initial reading of a digital voltmeter U_t corresponds to room temperature.

IT IS STRICTLY FORBIDDEN TO TOUCH THE INNER SURFACE OF THE CALORIMETER AND THE SURFACE OF THE TEST BODY WITH YOUR HANDS!

Task 1.Measurement of the time dependence of the temperature of the calorimeter with the sample

Using the holder, place the test sample *8* into the calorimeter *9*, unscrew the holder and close the calorimeter with the sample with the cover *10*.

Close the heater circuit by turning the knob 4 of the A- 5K rectifier. Set the operation mode by turning knob *5* to position“II ст ". Rotate the knob of potentiometer 6 to apply a voltage of 60 V to the heater coil (the supplied voltage is controlled with a voltmeter on the rectifier panel, and the current I_H in the heater circuit is measured by ammeter *7*).

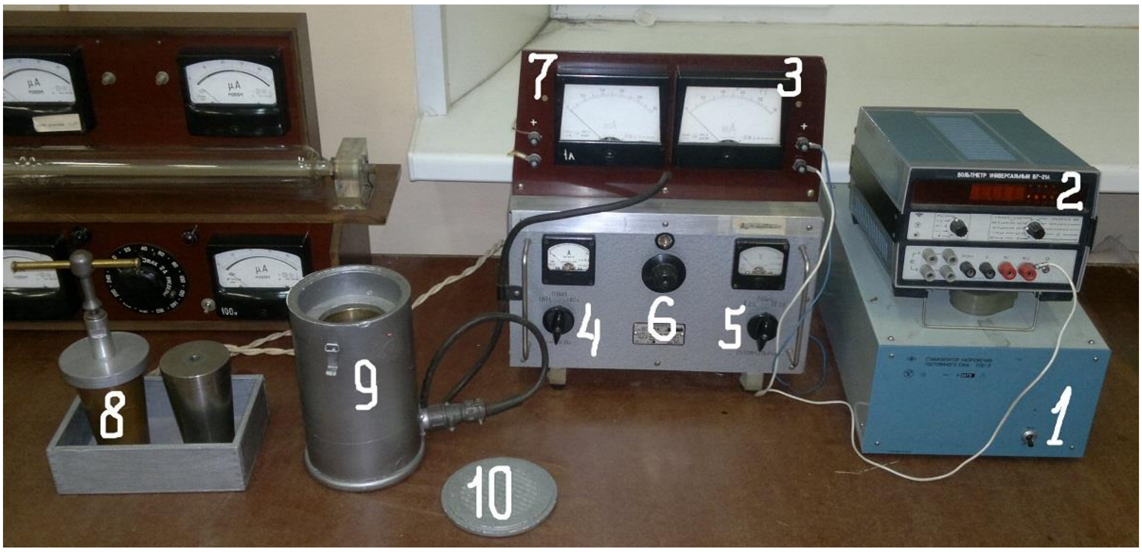

Fig. 4. Experimental setup

When the voltage U_t measured by a digital voltmeter, reaches 3.350 mV , start the stopwatch. Measure the dependence of U_t on time with a step of 0.020mV to a final value of 3.750 mV (a total of 20 points). During the measurement process, keep the heater current constant. For each value of U_t, calculate the corresponding temperature *t*. The results of measurements and calculations listed in the table.

U_t, mV	R_t, Ohms	t, ^oC	Calorimeter with sample		Empty calorimeter	
			τ, min.sec	τ, sec	τ, min.sec	τ, sec
3.350 3.370 … 3.750						

After completing the measurements, turn off the heater (knob 4), open the calorimeter cover, and remove the body using the holder. Cool the calorimeter until the U_t value is just below 3.350 mV.

Task 2. Measurement of the time dependence of the temperature of an empty calorimeter

Close the empty calorimeter with a lid and take the same measurements as in Task 1. After taking measurements, turn off the unit and open the lid of the Calorimeter.

Task 3. Determination of the sample heat capacity

Draw graphs of dependency of temperature increments of calorimeter with a sample and an empty calorimeter on time. Using graphs find the specific and molar heat capacity of the sample under study. For calculations use five different values of Δt. Estimate the accuracy of the results. Compare the obtained values of heat capacities to the table values (see a reference book) and to the predicted ones by the law of Dulong and Petit.

QUESTIONS AND EXERCISES

1. What is the molar heat capacity of a solid dielectric crystal, according to the classical theory of heat capacities? Calculate the molar heat capacity C_V for boiled salt NaCl in the classical approximation.

2. How does the heat capacity of a crystal change with decreasing temperature? Does the classical theory explain this change?

3. What are the main points of the Debye theory of the heat capacity of the crystal lattice?

4. Debye temperature for carbon (diamond) $\Theta =$ 200 K. What is its molar and specific heat capacity at 300 K?

5. Using the graphic $\frac{C_V}{3R} = f\left(\frac{T}{\Theta}\right)$ given in the Appendix to work, find the Debye temperature of copper.

6. What statistical distribution describes electron gas in a metal? What does the Fermi temperature depend on?

7. How to estimate the contribution to the heat capacity of a metal of conduction electrons: a) based on the classical theory; b) based on quantum theory? How does the heat capacity of an electron gas depend on temperature?

8. Calculate the Fermi energy and Fermi temperature for copper. Take the number of free electrons equal to the number of atoms. Copper density $\rho = 8.94\ 10^{3} \cdot$ kg / m$^{3.}$

9. Analyze how the following factors affect the value of the heat capacity obtained as a result of the experiment: a) non-uniform heating of the sample; b)the heat loss difference when we heat a full and empty calorimeter .

Appendix

Dependency graph $\frac{C_V}{3R} = f\left(\frac{T}{\Theta}\right)$