EXPERIMENTAL STUDY OF THE THERMAL CONDUCTIVITY OF WEAKLY ABSORBING LIQUIDS IN LAYERS TRANSPARENT TO INFRARED RADIATION

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UDC 536.22

The thermal conductivities of a number of organic liquids are determined by a transient method under irregular thermal conditions.

A great deal of experimental work has been carried out in the last few years in connection with the influence of radiation on thermal-conductivity measurements in semitransparent media, a category including the majority of liquids. Measurements have most frequently been based on the most widely accepted steady-state methods (plane layers, coaxial cylinders, heated filaments). Theoretical analysis [1–5] and a considerable number of experimental investigations [3, 5–8] show that the influence of radiation expresses itself as a dependence of the thermal conductivity on the thickness of the layer used for the measurements. The molecular thermal conductivity is approximately obtained on extrapolating this relationship to zero layer thickness.

There are certain possible ways of eliminating the effect of radiation on the results of thermal-conductivity measurements; these include the so-called transient methods, especially those involving irregular thermal conditions. These methods are most frequently realized by the transient heating of a metal filament immersed in the liquid, with simultaneous recording of its temperature. The use of very thin filaments with a low intrinsic heat capacity enables the thermal conductivities to be measured quite rapidly, so that the region (layer) over which the measurement is carried out may be relatively small. For a broad class of weakly absorbing liquids, the thickness of this layer may be smaller than the mean free path of the photons characterizing infrared radiation. The radiative mechanism of heat transfer may then be almost entirely neglected, and the value of the thermal conductivity obtained under these specific conditions may be identified with the molecular thermal conductivity. The influence of radiative heat transfer then only appears as a loss of some of the heat from the surface of the heater and from the interior of the layer into which the transient temperature field penetrates. The total extent of these losses is small in the case of brief measurements and need not be taken into account.

The criterion of "transparency" as regards thermal radiation may be written in the form

$$\bar{\ell} > l^*,$$  \hspace{1cm} (1)

where

$$\bar{\ell} = \frac{1}{k_s} \cdot \frac{\partial u}{\partial T} \, dv / \int \frac{\partial u}{\partial T} \, dv, \quad l^* = (at)^{1/2}.$$  

In order to estimate $\bar{\ell}$ it is sufficient to limit consideration to monochromatic radiation of frequency $\nu$, corresponding to the maximum of the Planck distribution function at the particular temperature. In this case $\bar{\ell} = 1/k_s' \nu$, and inequality (1) may be expressed in the form

Thus, subject to the condition that the layer should be "transparent" with respect to infrared radiation, the choice of the period of measurements is determined by the parameter $1/k^2_{\nu_0} a$. For example, the numerical value of the parameter is 34 msec for toluene and 840 msec for CCl$_4$.

The filament placed in the test liquid is heated by an electric current. On using rectangular current pulses, creating a steady thermal flux $q_I$ in unit length of the filament, the law of temperature variation in the filament is determined [10] by the relationship

$$\Delta T = \frac{q_I}{4\pi\kappa} \ln \frac{4at}{r^2c},$$

valid for fairly small values of the parameter $r^2c/4at$. From Eq. (3) we derive an expression for the temperature increment of the filament between the instants $t$ and $t_0$:

$$\Delta T(t) - \Delta T(t_0) = \frac{q_I}{4\pi\kappa} \ln \frac{t}{t_0}.$$

The thermal flux was generated in a platinum filament ($r = 2 \mu$). The type of filament regularly produced by industry was rolled into a copper sheath of 25-$\mu$ radius. In order to create a probe, this was set in a special glass base (Fig. 1). The points of soldering the filament to the current lead and the contact between the filament and the base were covered with paraffin, and then the base and filament were immersed in a solution of nitric acid. After etching away the copper sheath from the open parts of the filament and washing in acetone, the probe so prepared was placed in toluene in order to dissolve the paraffin. The total length of the open platinum filament was about 150 mm.

The resistance of the filament was incorporated into a bridge circuit (Fig. 2). Voltage pulses of specified amplitude and length were shaped by means of a key based on a KT-802 transistor. The pulse length was specified by means of a rectangular pulse generator G of the G5-6A type. In order to "decouple" the circuit from the ground, transformer coupling was employed between the generator output and the base-emitter junction of the transistor. An S1-15 oscillograph was used to indicate the signals from the bridge diagonal. Between the generator and the oscillograph was a delay line DL creating a time displacement between the tripping of the oscillograph and the instant at which the voltage pulse acted upon the bridge circuit.

Let us consider the measurement of the instantaneous values of filament resistance during transient heating. Before the onset of the measurements the bridge resistances were chosen in such a way that the following relationship was satisfied:

$$\frac{R_1}{R_{10}} = \frac{R_2}{R_3} = 1.$$

As soon as the pulse operates, the filament temperature rises and the bridge circuit loses balance. Because of the delay line between the generator and the oscillograph, the oscillograph screen only records part of the temperature signal from the filament. When pulses arrive periodically (at a frequency chosen subject to the condition that the temperature field created by the previous pulse should vanish almost completely in the

Fig. 1. Experimental cell:
1) current leads; 2) soldering points; 3) glass base; 4) working part of filament; 5) section of filament in copper sheath.