Laboratory work № 2.27

DETERMINATION OF THE THERMAL CONDUCTIVITY COEFFICIENT OF SOLID

Purpose of the work: study of the phenomenon of thermal conductivity and determination of the thermal conductivity coefficient of various rocks.

Theory and method of measurements

Thermal conductivity is the process of transferring internal energy from more heated parts of the body to less heated parts. This process is carried out by chaotically moving body particles (atoms, molecules, electrons, etc.). Such heat transfer can occur in any bodies with a non-uniform temperature distribution, but the mechanism of heat transfer will depend on the state of aggregation of matter.

In gases and liquids, it occurs through the collision of particles with each other, as well as through the diffusion of molecules and atoms. In metals, thermal conductivity occurs as a result of the diffusion of free electrons and partially – elastic vibrations of the crystal lattice. In solid – dielectrics, mainly due to elastic vibrations of the crystal lattice.

In this work, the thermal conductivity of a solid is investigated.

Solids are divided into crystalline and amorphous. In crystals, atoms and molecules occupy certain ordered positions in space, forming the so-called spatial crystal lattice.

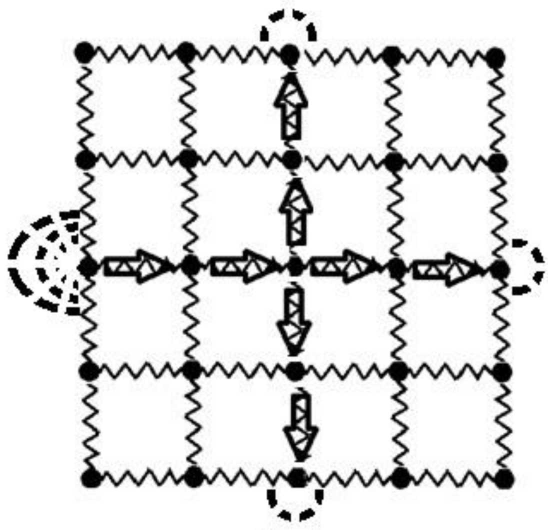
Fig. 1.

The forces that tend to keep atoms in equilibrium can be approximately considered proportional to their displacements. It is as if the atoms were bound by elastic springs.

Thermal conductivity of crystals can by explained as follows. An increase in the vibration amplitude of particles in a hotter place due to the interaction forces causes an increase in the vibration amplitude of neighboring particles. Due to the bond between particles, heat tends to a uniform distribution over the volume of the crystal. This leads to equalization of temperatures.

Let at two neighboring points of the bode the temperatures are equal to T and ($T+dT$), while the points are at a distance dx (Fig. 2). Then the ratio dT/dx will characterize rate of temperature drop. It is called *the temperature gradient*.

The basic law of thermal conductivity (Fouriet s law): the heat that passes through a layer of thickness dx, area S at the temperature difference at the boundaries of the layer dT, is proportional to the gradient of temperature dT/dx, area S and time dt:

$$dQ = -\lambda \frac{dT}{dx} S \cdot dt \,. \tag{1}$$

Here λ is *the coefficient of thermal conductivity* (the modern name is *thermal conductivity*). The minus sign indicate that the energy transfer occurs in the direction of a lower temperature, in the direction opposite to the temperature gradient.

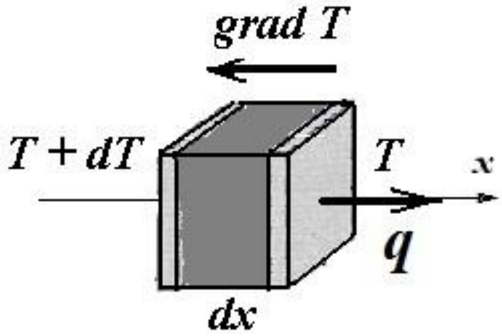

Fig. 2.

The temperature gradient is a vector characterizing the rate of temperature change in space and directed towards the most rapid increase in temperature (Fig.2). If the temperature change only along some one direction, for example, the x-axis, then the numerical value of the gradient is simply the derivative

$$(grad\ T)_x = \frac{dT}{dx}.$$

If in formula (1) we take $dT = 1\,\mathrm{K}$, $S = 1\,\mathrm{m}^2, t = 1\,\mathrm{s}$, $dx = 1\,\mathrm{m}$, then $\lambda = dQ$. Therefore, thermal conductivity is a physical quantity that is numerically equal to the heat that is transferred through a unit area of a layer with a thickness of one unit per unit of time with a temperature difference of one degree.

Rewhite equation (1) differently

$$\frac{dQ}{dt} = -\lambda \frac{dT}{dx} S. \qquad (2)$$

The expression *dQ/dt* is the thermal energy that is transferred through the surface of the sample per unit of time, that is, the thermal power.

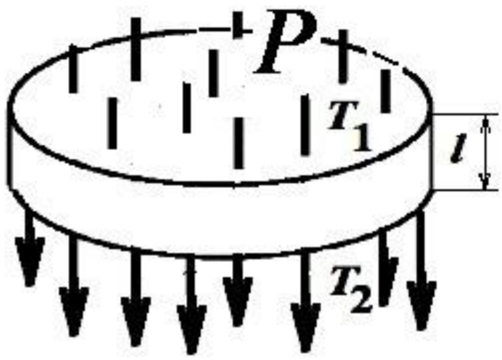

Fig. 3.

You can maintain stationary, i.e. time-invariant thermal flux through a flat test sample. For this, it is necessary to supply a constant thermal power *P* to one of its surface (in Fig.3 – to the top). The lower surface of the sample will have a lower temperature $T_2 < T_1$.

From (2) follows the equation for the thermal conductivity

$$\lambda = -\frac{P}{\left(\frac{dT}{dx}\right) S}. \qquad (3)$$

Since by definition $dT = T_2 - T_1$, then $-dT = T_1 - T_2$. Replacing $dx = l$, we obtain the formula for determining the thermal conductivity

$$\lambda = \frac{Pl}{(T_1 - T_2)S} = \frac{Pl}{|\Delta T| S}. \qquad (4)$$

Description of device

Laboratory device is made in the form of two units: working element and instrument cluster.

The working element is designed to create a stationary heat flow through the sample and measure the temperature difference at the ends of the sample (Fig.4). The instrument unit is designed to obtain a constant voltage on the heater, process information from the sensors, and present it in digital form.

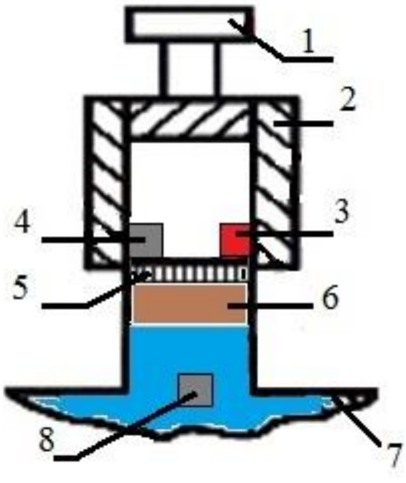

Fig. 4.

A test sample of rock in the form of the thin disk *6* is clamped with a screw *1* between the heater (electric heater *3* + copper disk *5*) and the refrigerator *7*.

The heater creates the heat flux. Refrigerator *7* is designed to remove the heat that has passed through the test sample and maintain the temperature of the lower surface of the sample constant.

The temperature on the upper and lower surface of the sample is measured by temperature sensors (thermocouples) *4* and *8*.

The working element is designed in such a way that almost all the heat generated by the heater flows through the plane-parallel sample perpendicular to its base area. Outside the element is thermally insulated (*2* – thermal insulation). However, some of the heat escape through the thermal insulation, as well as the lateral surface of the disk due to thermal radiation.

Accounting for heat loss gives a working formula for determining thermal conductivity

$$\lambda = \frac{(P - P_{\text{loss}})l}{\Delta T S}, \qquad (5)$$

Where P_{loss} – power losses. Power loss is proportional to the temperature difference, it is determined according to the graph attached to the device.

№	P, W	P_{loss}, W	l, m	S, m^2	ΔT, K	λ_i, Вт/(m·K)	$<\lambda>$, W/(m·K)	$\Delta\lambda_i$ W/(m·K)	$S_{<\lambda>}$	$t_{\alpha,n}$	$\Delta\lambda$, W/(m·K)	E, %
1												
2												
3												