HEAT CONDUCTION

OBJECTIVE

Measure conduction of heat in metal bars.

EXERCISES

- **Measure how temperature changes with time along metal bars which are heated at one end but remain cool at the other in both dynamic and steady states.**
- **Measure the flow of heat in the steady state.**
- **Determine the heat conductivity of the material from which the bar is made.**

SUMMARY

Conduction of heat involves heat being transferred from a hotter part of an object to a colder area by means of the interaction between neighbouring atoms or molecules, although the atoms themselves remain in place. In a cylindrical metal bar with ends maintained at different temperatures, a temperature gradient will emerge along the bar after a while. The temperature decreases uniformly from the warm end to the cold end and a constant flow of heat arises through the bar. The way the situation changes from a dynamic state to a steady state is observed by means of repeated measurements to determine the temperatures at various measurement points. The metal bars are electrically heated so that the flow of heat in the steady state can be determined from the electrical power supplied.

REQUIRED APPARATUS

Quantity	Description	Number
1	Heat Conduction Equipment Set	**1017329**
1	Heat Conducting Rod Al	**1017331**
1	Heat Conducting Rod Cu	**1017330**
1	DC Power Supply 0 – 20 V, 0 – 5 A (230 V, 50/60 Hz)	**1003312** **or**
	DC Power Supply 0 – 20 V, 0 – 5 A (115 V, 50/60 Hz)	**1003311**
1	Digital Quick Response Pocket Thermometer	**1002803**
1	K-Type NiCr-Ni Immersion Sensor, -65°C – 550°C	**1002804**
1	Pair of Safety Experimental Leads, 75cm, red/blue	**1017718**
1	Set of 10 Beakers, Low Form	**1002872**

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GENERAL PRINCIPLES

Heat can be transported from a hotter area to a colder one by conduction, radiation or convection. Conduction of heat involves heat being transferred from a hotter part of an object to a colder area by means of the interaction between neighbouring atoms or molecules, although the atoms themselves remain in place. For instance, when a metal bar is heated, the atoms at the hotter end vibrate more vigorously than those at the cooler end, i.e. they vibrate with more energy. Energy is transferred due to collisions between neighbouring atoms, passing the energy from one atom to another and thereby conducting it along the bar. Metals are particularly good conductors of heat since collisions also occur between atoms and free electrons.

In a bar with a cross-sectional area of A, when the ends are maintained at different temperatures, after a while a temperature gradient emerges along the bar, whereby the temperature decreases uniformly along the length towards the cold end. In a time period dt a quantity of heat dQ flows through the cross-section of the bar and there arises a constant flow of heat P_Q:

(1) $$P_Q = \frac{dQ}{dt} = \lambda \cdot A \cdot \frac{dT}{dx}$$

P_Q: Flow of heat (measured in watts)
A: Cross-sectional area of bar
λ: Heat conductivity of material from which the bar is made
T: Temperature, x: Coordinate of length along the bar

Before the constant temperature gradient arises, the temperature distribution at a specific time t is given by $T(x,t)$, which gradually becomes closer to the steady state. The following differential equation then applies

(2) $$\lambda \cdot \frac{\partial^2 T}{\partial x^2}(x,t) - c \cdot \rho \cdot \frac{\partial T}{\partial t}(x,t) = 0$$

c: Specific heat capacity
ρ: Density of material from which bar is made

In the steady state the situation is in agreement with equation (1)

(3) $$\frac{\partial T}{\partial t}(x,t) = 0 \quad \text{and} \quad \lambda \cdot \frac{\partial T}{\partial x}(x,t) = const. = \frac{P_Q}{A}$$

In this experiment the bar is heated at one end by electrical means. An electronically regulated source of heat provides the bar with an amount of heat which can be determined by measuring the heater voltage U and current I:

(4) $$P_{el} = U \cdot I$$

Electronic regulation of the current ensures that this end of the bar rapidly reaches a temperature of about 90°C and this temperature is then maintained constant.
The other end of the bar is kept at the temperature of melting ice or simply water at room temperature via its cooling baffles. This allows the heating to be determined by calorimetry.
An insulating sleeve minimises the loss of heat from the bar to its surroundings and ensures the temperature profile is more linear in the steady state.
Using an electronic thermometer that determines temperature within a second, temperatures are measured at pre-defined measurement points along the bar. Both a copper bar and an aluminium bar are provided.

EVALUATION

The flow of heat PQ corresponds to the electrical power P_{el} minus a small quantity of power dissipated due to losses P_l: $P_Q = P_{el} - P_l$

Therefore: $$\lambda = \frac{P_{el} - P_l}{A} \cdot \frac{L}{T(0) - T(L)}$$

(L: Distance between selected temperature measurement points)

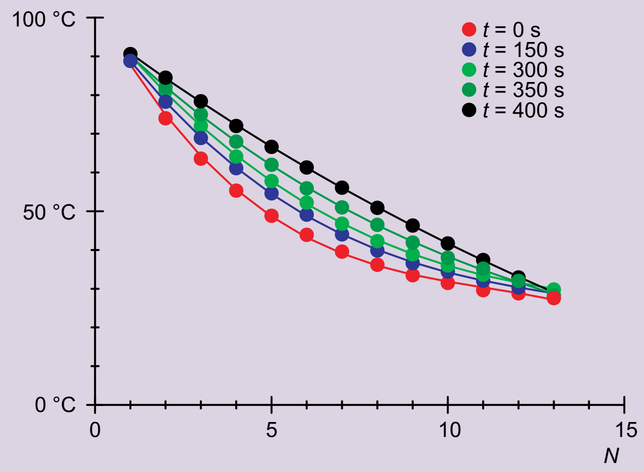

Fig. 1: Temperatures along the aluminium rod in five sets of measurements made at time intervals of 150 s.