A01-131P-Y21

Thermal Conductivity Apparatus

Purpose

Measure the Thermal conductivity coefficient of metals.

Theory

When two parts of a material is at different temperature, energy can transfer from high temperature to low temperature by the collision of phonons and electrons. As shown in **Figure 2-1**, the length of an object is L and its cross-sectional area is A. One side of the temperature of the object is T_1 and temperature of another side is T_2. The heat flowing through the object in a period of time is Q. This experiment uses metal rods to conduct experiments. Features we observed are listed as below:

1. In per unit of time, the transferred heat is directly proportional to the temperature difference of two sides of metal rods ($\triangle T = T_1 - T_2$).
2. In per unit of time, the transferred heat is directly proportional to the cross-sectional area of metal rod.
3. In per unit of time, the transferred heat is inversely proportional to the distance between two sides of metal rod.

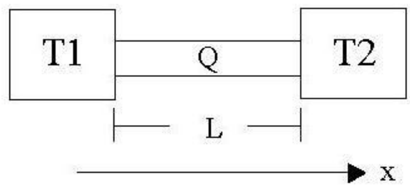

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Figure 2-1

The experimental result can be expressed in equation (1)

$$\frac{dQ}{dt} = -\lambda A\left(\frac{dT}{dx}\right) \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

The heat dQ flows in per unit of time dt is directly proportional to the cross-sectional area A of metal rod and is directly proportional to the temperature gradient $\frac{dT}{dx}$ of cross-sectional area. λ is the thermal conductivity coefficient (thermal conductivity). $\frac{dT}{dx}$ means heat transfers at one-dimensional temperature gradient. If the value is minus, the direction temperature gradient is opposite to the direction that heat transfers.

The temperature distribution of metal rod is related to the distance and spacing. It follows the conduction equation.

$$\frac{dT}{dt} = \left(\frac{\lambda}{\rho \cdot c}\right)\left(\frac{d^2T}{dx^2}\right) \quad \cdots\cdots\cdots\cdots\cdots(2)$$

ρ is density and is specific heat. If the length of metal rod is L and the temperature of two sides are T_1 and T_2 , then

$$\frac{dT}{dt} = 0 \quad \cdots\cdots\cdots\cdots\cdots(3)$$

From equation (2) and (3), we know that

$$T(x) = \frac{T_2 - T_1}{L} \cdot x + T_1 \quad \cdots\cdots\cdots\cdots\cdots(4)$$

The thermal conductivity unit in this experiment is **cal / cm・s・℃**. The theoretical thermal conductivity of aluminum rode is **0.37 cal / cm・s・℃.**

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Instruments

No.	Accessory	Qty	No.	Accessory	Qty
1.	Microcomputer temperature controller	1	2.	Thermocouple heater	1
3.	Aluminum stand	1	4.	Aluminum base (including legs)	1
5.	Metal rod set-down device (including stopper)	1	6.	Metal rods to be measured	2
7.	Calorimeter holder (Including lid stopper)	1	8.	Calorimeter	1
9.	Thermometer holder	2	10.	Digital electronic thermometer	3

Figure 3-1

Procedure

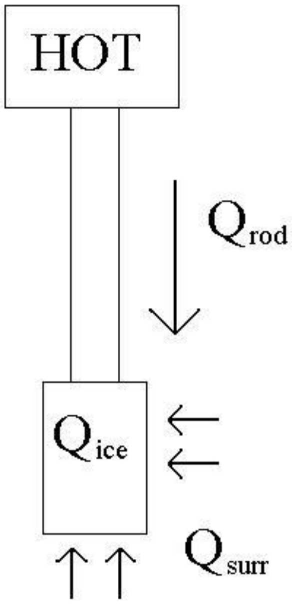

Figure 4-1 Experimental system

In **Figure 4-1**, the heat (Qice) in the calorimeter is the total of Q_{surr} which is from the environment to the calorimeter and the Q_{rod} which is obtained from heat source to the calorimeter via the aluminum rod.
The experiment will first calculate the heat capacity of calorimeter. Take away the ice in the calorimeter when the temperature in the system is stable. Measure the rising temperature in the calorimeter to calculate Q_{ice} and then use the same water amount to measure Q_{surr}. The equation can be written as:

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$$Q_{rod} = Q_{ice} - Q_{surr}$$

Use cross-sectional area A of metal rod, the distance x of two holes on the metal rod and the temperature difference T to calculate thermal conductivity λ of metal rod.

(I) Calculate the heat capacity of calorimeter

1. Take hot water (60-80 ℃). Record the temperature T_W and mass M_W of hot water. Pour the water into empty calorimeter. When the temperature is stable, record the temperature T_M and room temperature T_R. Use equation (5) to calculate the heat capacity of calorimeter

$$C_C = c_W \cdot M_W \cdot \frac{T_W - T_M}{T_M - T_R} \quad \cdots\cdots\cdots\cdots (5)$$

C_C : Heat capacity of calorimeter

C_W : Specific heat capacity of water

M_W : Mass of water

T_W : Initial temperature of hot water

T_M : Mixing temperature

T_R : Room temperature

The unit of Heat capacity of calorimeter is cal / ℃.

(A calorimeter is not composed of one single material so we can only calculate the whole heat capacity of calorimeter. The operation method is different from person to person so there is a ±25% difference on the calculation of heat capacity of calorimeter.)

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(II) Measurement of Q_{ice} and thermal conductivity of metal rod in per unit time

1. The experimental setup is shown in **Figure 3-1**. (Apply thermal grease on the contact are of metal rod and the heater)

2. Put the calorimeter cup into the insulated cup and add cold water till the water touches 1mm of the metal rod when closing the lid. Put in ice. Make sure there are ice cubes when the temperature of two sides of metal rod are stable. This step is to prevent experimental errors. Close the lid of insulated cup and put in thermometer.

(Take out the ice when the temperature of two side of metal rod are stable. Make sure the metal rod is in the water of calorimeter.)

3. Turn on the microcomputer temperature controller. Set up the temperature and put the metal rod into the cold water with ice. The advised temperature of the controller is 70-80 ℃. Do not set the temperature over 110℃.

4. When turning on the controller, the temperature of two holes on the metal rod will start to change. During the measurement, if the temperature of the calorimeter rises, stir the calorimeter cup for 5 seconds to keep the temperature stable so the whole system can reach balance.

5. When the controller reaches the setup temperature and is stable (temperature of two holes are stable when they maintain ±1℃ for 2-3 minutes) and the cold water maintains its original temperature, record temperature of two holes as T1 and T2.

6. Take out ice cubes when the temperature is stable. Put the calorimeter back so the metal rod is in the water of calorimeter.

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(Step 2 is very important. Make sure the rod is in the water in step 2.)

Start timing 15 minutes when the temperature starts dropping until the temperature reaches its lowest. You can stir the cold water in the calorimeter as step 4. (The amount of absorbed heat during stirring is very small so it can be neglected.)

7. Record the initial temperature T3 when putting metal rod in the water. Record the temperature T4 after 15 minutes.

(Depends on the situation, you can prolong the measuring time. Suppose the measuring time is 20 minutes. T4 is the temperature after 20 minutes. The initial temperature T3 is measured by pushing back 15 minutes.)

8. Measure the mass M_i of cold water in the calorimeter. Use equation (6) to measure the total thermal the calorimeter absorbed in 15 minutes from the environment and heater on the metal rod.

$$Q_{ice} = (c_W \cdot M_i + Cc) \cdot \Delta T \cdots\cdots\cdots\cdots (6)$$

$$\triangle T = (T_3 - T_4) / t$$

Q_{ice}： Total thermal (metal rod + environment) the calorimeter acquired per minute

T_3： Initial temperature of cold water when putting the metal rod in the calorimeter

T_4： Final temperature of cold water when putting the metal rod in the calorimeter

C_c： Heat capacity of calorimeter

C_W： Specific heat of water

M_i： Mass of cold water in the calorimeter

t： Time after taking out ice cubes

9. Use this cup to conduct experiment of heat in the calorimeter acquired from environment.

(III) Heat in the calorimeter acquired from environment.

1. Put the colorimeter (with cold water) to the insulated cup. Close the lid and put in the thermometer. Record the temperature change △t of cold water every minute. Use equation (7) to calculate the heat absorb from the environment per minute.

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$$Q_{surr} = (c_W \cdot M_i + C_c) \cdot \Delta t \cdots\cdots\cdots\cdots (7)$$

Q_{surr}： Heat in the calorimeter acquired from environment

C_W： Specific heat of water

C_c： Heat capacity of calorimeter

M_i： Mass of cold water in the calorimeter

△t： Rising temperature of cold water in the calorimeter per minute

(IV) Calculation of thermal conductivity coefficient

(8) to calculate the thermal conductivity coefficient λ of metal rod.

$$Q_{rod} = -\lambda A\left(\frac{dT}{dx}\right) = Q_{ice} - Q_{surr} \text{...........} (8)$$

Q_{rod}： Net heat of metal rod conduction

Q_{ice} ： Absorb heat of metal rod in the cold water

Q_{surr}： Heat of calorimeter from environment

A： Cross-sectional area of metal rod

dT ：T_1- T_2

dx： Distance of two holes on the metal rod

λ： Thermal conductivity coefficient of metal rod.

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