Physics HL Internal Assessment

Research on Thermal Conductivity of Wood and Stainless Steel

Research question: "How does the thermal conductivity of wood compare to that of stainless steel?"

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1 Introduction and personal engagement

In winter, we often encounter a phenomenon in our lives. In the same environment, the steel handrails of staircase handrails are much cooler than wooden handrails, and tile floors in the same environment are much cooler than wooden floors. In the same environment, they should theoretically have the same temperature, but why is there such a big difference in the feeling?

For this reason, I checked the information and found that the difference in the touch feeling of different materials at the same temperature is mainly due to the different heat transfer performance of different materials. In winter, steel and wood are at the same ambient temperature. The temperature of steel and wood is the same as the ambient temperature, which is lower than the temperature of human hands. When people touch steel or wood with their hands, the heat will be conducted to steel or wood, and the thermal conductivity of steel is better than that of wood, and more heat will be taken away from human hands. This is why steel is colder to the touch than wood. The main reason for the difference in thermal conductivity between steel and wood is the difference in thermal conductivity between the two. Thermal conductivity is an important physical quantity reflecting the thermal performance of materials. Materials with large thermal conductivity and good thermal conductivity are called good conductors, and materials with low thermal conductivity and poor thermal conductivity are called poor conductors. Generally speaking, the thermal conductivity of metal is larger than that of non-metal, the thermal conductivity of solid is larger than that of liquid, and the thermal conductivity of gas is the smallest. I found this phenomenon aroused my great interest. For this reason, I want to experiment to test the difference between the thermal conductivity of steel and wood. The content of the experiment is mainly to measure the thermal conductivity of steel and wood, and compare with the standard value of thermal conductivity, and analyze the main reasons for the error. The main work is divided into the following parts:

1) First of all, consult relevant materials to understand the basic laws of the heat transfer process, the factors that affect the thermal conductivity, and the testing methods of thermal conductivity;

2) Then, based on the reference materials, design the experiment plan, establish the preliminary experiment process, and analyze the feasibility of the experiment;

3) Third, select appropriate experimental equipment and measuring equipment according to the experimental plan, and put forward specific experimental operation steps and specific matters for attention in the experiment according to the experimental process;

4) Fourth, carry out experiments according to the experimental process and experimental procedures, and obtain experimental results;

5) Finally, the experimental results are processed to calculate the thermal conductivity; the error analysis of the experimental data is carried out, the experimental conclusions are drawn, and the experimental prospects are made.

2 Exploration

2.1 Background information

2.1.1 Thermal conductivity and its influencing factors

The thermal conductivity λ reflects the heat transfer performance of a substance. The thermal conductivity refers to the heat transfer through an area of 1m2 within 1s for a material with a thickness of 1m under stable heat transfer conditions and a temperature difference of 1°C on both sides. The unit is W/(m·°C). Many factors affect thermal conductivity. For solids, liquids, and gases, the factors that affect thermal conductivity are also different. For solids, firstly, the thermal conductivity is related to the type of material, and the thermal conductivity of different solid materials varies greatly. Generally speaking, metals have better thermal conductivity than non-metals; secondly, it is also related to the structure of the material, which is also steel. The thermal conductivity of carbon steel and stainless steel will also be slightly different, and the thermal conductivity of wood of different structures will also be different; also, the thermal conductivity is related to the temperature, the thermal conductivity of the material is not static, but changes with temperature Function, generally speaking, the higher the temperature, the better the thermal conductivity of the material.

2.1.2 Fourier's law of heat conduction

Fourier's law of heat conduction is the basic law of heat conduction. This law states that under steady-state conditions, the amount of heat conduction Φ passing through a given cross-section per unit time is proportional to the material's the thermal conductivity λ, the temperature difference ΔT between two points perpendicular to the cross-sectional direction and the cross-sectional area A is inversely proportional to the distance d between the two points. which is:

$$\Phi = \lambda A \frac{\Delta T}{d} \quad (1)$$

Through learning and understanding, it is found that Fourier's law of heat conduction is very similar to Ohm's law. In the physics class electromagnetics, we have learned Ohm's law. Ohm's law describes that in the same circuit, the current I through a certain section of the conductor is proportional to the potential difference ΔV between the two ends of the conductor, and inversely proportional to the resistance R. which is:

$$I = \frac{V}{R} \quad (2)$$

The resistance is related to the resistivity ρ, the cross-sectional area A, and the length of the conductor L, namely:

$$R = \frac{\rho L}{A} \quad (3)$$

Combining equation (2) and equation (3) can get:

$$I=\frac{V}{\frac{\rho L}{A}}=V*\frac{A}{\rho L}=\frac{VA}{\rho L}=\frac{1}{\rho}*A*\frac{V}{L}=\sigma*A*\frac{V}{L} \quad (4)$$

σ is the conductivity of the material. In this way, we find that Fourier's law of heat conduction in heat conduction is surprisingly similar to Ohm's law in circuits. The current I in the circuit can be analogized to the heat conduction Φ in thermal conduction; the potential difference V in the circuit can be analogized to the temperature difference ΔT in thermal conduction, and the electrical conductivity in the circuit can correspond to the thermal conductivity λ in thermal conduction. In this way, through analogy, we can better understand Fourier's law of heat conduction.

2.2 Variables

Table 1: Independent variable

Names	Units	How are they controlled?
The temperature of the specimen	°C	The temperature at the bottom is adjusted using a water bath. The temperature at the top is adjusted using an icebag. Heat loss is also controlled using Insulation cotton.

Table 2: Dependent variable

Name	Unit	How are they controlled
The thermal conductivity of the specimen	W/(m·°C)	The thermal conductivity changes as the temperature changes.

Table 3: Control variables

Names	Units	How are they controlled?
the thermal resistance of the material	Ω	This experiment uses a constant temperature water bath; hence, the conductivity doesn't change
the cross-sectional area of the specimen	mm^2	The cross-sectional area of the specimen doesn't change since it will not melt, burn, or freeze during the experiment.
Distance between two adjacent platinum resistors	mm	The specimen doesn't go through expansion or minify; hence, this value doesn't change

2.3 Apparatus lists

Table 4 Material list

Name	Quantity
Constant temperature water bath	1
Ice water mixture bag	1
Insulation cotton	2 layers
Resistance thermometer	1
Multimeter	4
Iron Rub	1
Wood Rub	1

2.4 Precautions and considerations

1) In the experiment, the platinum resistance thermometer should be arranged as far as possible to ensure that the platinum resistance thermometer is on the same side of the specimen, and the spacing is 40mm.
2) In the experiment, when using a hammer to break the ice in the preparation of the ice-water mixture, take care of protective measures and be careful of hurting your hands.
3) Read the instruction manual carefully before using the thermostatic water bath, check whether the appearance is good, and confirm whether the plug is contaminated with water droplets when plugging in.
4) Pay attention to lead out the measuring line of the platinum resistance thermometer when wrapping the thermal insulation cotton, and do not knock the platinum resistance thermometer off when wrapping.
5) After the test, the heating section of the specimen is still at a high temperature. Replace the specimen to prevent burns.

2.5 Procedures

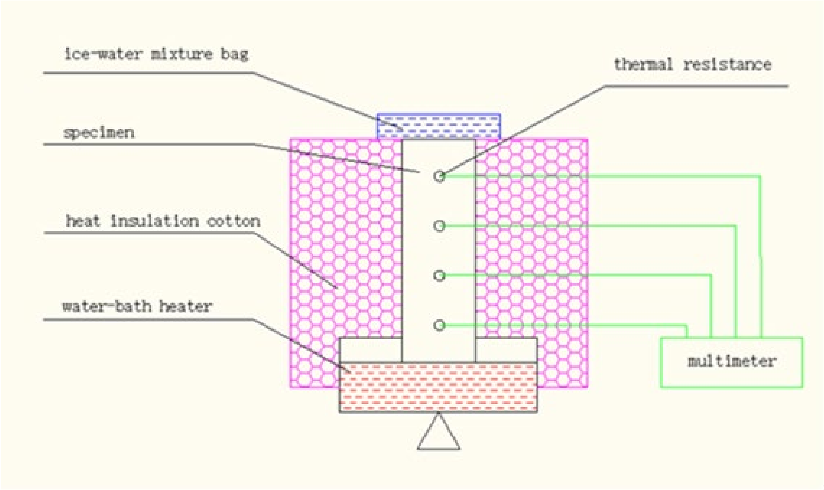

Figure 1: the experimental setup

1) First, use a ruler to divide the wood with a height of 100mm and 50mm of the radius into five points. A platinum resistance thermometer is arranged every 20mm along the same side of the specimen from the lower side, numbered by T1, T2, T3, and T4.

2) Prepare the ice water mixture bag. Put the mixed ice-water mixture into a sealed bag for later use.

3) Add water to the water bath to approximately two-thirds of the height of the inner volume of the pot.

4) Wrap black rubber-plastic insulation cotton around the specimen to reduce heat leakage during heat transfer.

5) Turn on the constant temperature water bath to preheat, set the temperature of the water bath to 80°C, and wait until the temperature is constant.

6) Place the ice-water mixture bag on top of the specimen and start the experiment.

7) In the experiment, the resistance values of the four platinum resistance thermometers are measured when the power and temperature of the bath remain constant.

8) During the experiment, observe the volume of ice in the ice-water mixture in real-time. When the volume of ice cubes is less than 1/4 of the volume of the ice-water mixture, the ice-water mixture bag should be replaced.

9) Test five times on wood and stainless steel.

3 Analysis

3.1 Raw data table

Table 5 Raw data record sheet for measuring the thermal conductivity of wood

Number of trials	The temperature of the bath/°C	The power of the bath/W ±2 W	T1 Resistance /Ω	T2 Resistance /Ω	T3 Resistance /Ω	T4 Resistance /Ω
1	80.5	10.9	125.6	125.6	113.1	106.7
2	79.6	12.9	125.2	119.1	112.6	106.5
3	79.2	12.1	125.2	118.9	112.5	106.1
4	80.0	11.0	125.1	118.9	112.8	106.0
5	80.0	12.0	125.3	118.8	112.5	105.6

Table 6 Raw data record sheet for measuring the thermal conductivity of steel

Number of trials	The temperature of the bath/°C	The power of the bath/ W ±2 W	T1 Resistance/ Ω	T2 Resistance/ Ω	T3 Resistance/ Ω	T4 Resistance/ Ω
1	80.3	105.2	125.6	119.4	112.4	106.2
2	80.6	105.7	125.3	119.1	112.1	106.1
3	79.9	100.7	125.3	118.8	112.3	106.5
4	80.8	103.7	125.6	119.6	113.2	106.5
5	80.1	104.7	125.4	119.1	112.3	105.8

3.2 Process data table

Checking the temperature corresponding to the resistance value of the platinum resistance according to the PT100 platinum resistance indexing relationship table. The results are summarized in the following table:

Table 6 Different temperature of the wood

Number of trials	The power of the bath/W ±2 W	T1 Temperature/°C ±0.5 °C	T2 Temperature/°C ±0.5 °C	T3 Temperature /°C ±0.5 °C	T4 Temperature /°C ±0.5 °C
1	10.9	65.1	49.0	33.2	17.1
2	12.9	64.0	48.5	31.9	16.5
3	12.1	64.0	47.9	31.8	15.6
4	11.0	63.8	48.0	32.6	15.3
5	12.0	64.3	47.8	31.8	14.3

Table 7 Different temperature of the steel

Number of trials	The power of the bath/ W	T1 Temperature /°C ±0.5 °C	T2 Temperature/ °C ±0.5 °C	T3 Temperature/ °C ±0.5 °C	T4 Temperature/ °C ±0.5 °C
1	105.2	65.1	49.3	31.5	15.8
2	105.7	64.1	48.5	30.8	15.4
3	100.7	64.3	47.8	31.2	16.4
4	103.7	65.1	49.7	33.5	16.4
5	104.7	64.6	48.5	31.4	14.7

3.3 Sample calculations

To reduce the error generated in the temperature measurement process, we measure the temperature values at the four points of the specimen, and then use the method of successional difference to calculate can significantly reduce the error.

$$\Phi = \lambda A \frac{\Delta T}{d} \text{(The original equation)}$$

$$\Phi = \lambda A\frac{T_1 - T_4}{d}$$ (The equation calculated without using successional difference)

The temperature at the bottom is T1, the temperature of T4 is measured at the top of the specimen. Using the successional difference, the temperature difference is much accurate when $(T_1 - T_3) + (T_2 - T_4)$. Because between the positions of measurements $(T_1 - T_3)$, the distance between them will be 2d. Similarly, the distance between T2 and T4 is 2d. The total separation resulted from such calculation will be 4d. Therefore, the equation is reorganized into:

$$\Phi = \lambda A\frac{(T_1 - T_3) + (T_2 - T_4)}{4d} \quad (5)$$

Because the heat generated from the water bath is transferred in an isolated environment, it is fair to assume that the power is absorbed by the specimen fully. By making the thermal conductivity an individual term, the equation can be rewritten as:

$$\lambda = \frac{4\Phi d}{A(T_1 - T_3 + T_2 - T_4)} \quad (6)$$

Using this equation and the temperature result, the thermal conductivity can be calculated. The uncertainty of the thermal conductivity is calculated:

$$\frac{\triangle\lambda}{\lambda} = \left|\frac{\triangle p}{p}\right| + \left|\frac{\triangle d}{d}\right| + \left|\frac{\triangle A}{A}\right| + \left|\frac{|\triangle T_1| + |\triangle T_2| + |\triangle T_3| + |\triangle T_4|}{|T_1 - T_3 + T_2 - T_4|}\right| \quad (7)$$

For wood:

$$\left|\frac{\triangle p}{p}\right| = \left|\frac{2}{10.9}\right| = 0.183 = 18.3\% \quad (8)$$

$$\left|\frac{\triangle d}{d}\right| = \left|\frac{0.02}{100}\right| = 0.02\% \quad (9)$$

$$\left|\frac{\triangle A}{A}\right| = 2 * \left|\frac{\triangle d}{d}\right| = 2 * 0.02\% = 0.04\% \quad (10)$$

$$\left|\frac{|\triangle T_1| + |\triangle T_2| + |\triangle T_3| + |\triangle T_4|}{|T_1 - T_3 + T_2 - T_4|}\right| = 4 * \frac{0.5}{64} = 3.125\% \quad (11)$$

Both power and temperature are taken values of 10.9W and 64℃ for calculating maximum uncertainty. The percentage uncertainty of thermal conductivity of wood is

$$\frac{\triangle\lambda}{\lambda} = 18.3\% + 0.02\% + 0.04\% + 3.125\% = 21.485\%$$

Using the same method, the percentage uncertainty of the steel is about:

$\frac{\Delta\lambda}{\lambda} = 1.99\% + 0.02\% + 0.04\% + 3.125\% = 5.175\%$.

Table 6 Calculation result of thermal conductivity of wood

Number of trials	The power of the bath/W ±2 W	Thermal conductivity W/(m·°C)
1	10.9	1.74 ±0.37
2	12.9	2.05 ±0.44
3	12.1	1.91 ±0.41
4	11.0	1.75 ±0.37
5	12.0	1.85 ±0.40
The average thermal conductivity: (1.74+2.05+1.91+1.75+1.85)/5=1.86 W/(m·°C)		

In the above calculation, the cross-section area A of wood is

$\pi r^2 = \pi(\frac{50}{1000})^2 = 0.007m^2$, the amount of heat conduction Φ is always equal to the power of the bath provided during the experiment. Using equation 6, The thermal conductivity of trail 1 equals to:

$$\lambda_1 = \frac{4*10.9*(20/1000)}{\pi(50/1000)^2(65.1-33.2+49-17.1)} = \frac{0.872}{0.501} = 1.74W/(m^oC)$$

$$\lambda_2 = \frac{4*12.9*(20/1000)}{\pi(50/1000)^2(64-31.9+48.5-16.5)} = \frac{1.032}{0.503} = 2.05W/(m^oC)$$

Using the above calculation, the thermal conductivity of wood can be calculated. the average thermal conductivity can be found to be $\overline{\lambda}$=1.86W/(m·℃).

Table 7 Calculation result of thermal conductivity of steel

Number of trials	The power of the bath/W	Thermal conductivity W/(m·°C)
1	105.2	15.97 ±0.82
2	105.7	16.21 ±0.84
3	100.7	15.90 ±0.82
4	103.7	16.28 ±0.84
5	104.7	15.92 ±0.82
The Average thermal conductivity:		

(15.97+16.21+15.9+16.28+15.92)/5=16.06 W/(m·°C)

Using the above calculation, the thermal conductivity of steel can be calculated. the average thermal conductivity can be found to be $\overline{\lambda}$=16.06W/(m·℃).

3.4 Error analysis

First of all, platinum resistance is used to measure the temperature in the experiment. The temperature measurement of the platinum resistance will bring errors to the calculation results. Also, the use of a multimeter to measure the resistance of the platinum resistance will cause errors.

Secondly, in the experiment, it is approximated that the real-time power of the constant temperature water bath is the heat conduction on the specimen. In practice, the real-time power of the constant temperature water bath must be greater than the heat conduction on the specimen. This is because of the heat generated by the constant temperature water bath. It will inevitably be dissipated to the external environment.

Finally, the real-time power and real-time temperature of the constant temperature water bath will also have certain errors, which will bring errors to the experimental results.

Comparing the error of testing wood and stainless steel, the deviation of the five measurements of stainless steel and the average value is less than 1.5%, while the wood has 10%. This is mainly because the heat transfer of wood in the test environment is very small, and the constant temperature water bath the real-time power of the pot has a large error.

4 Conclusion

In conclusion, comparing the thermal conductivity of wood with the thermal conductivity of stainless steel, I have found that the thermal conductivity of stainless steel is 8.63 times that of wood.

5 Evaluation

5.1 Potential improvements

Through the above error analysis, to improve the accuracy of measuring the thermal conductivity of wood, we can choose thicker specimens and shorter specimens, which can improve the accuracy of heat transfer measurement, thereby improving the measurement of wood thermal conductivity accuracy.

The selection of more accurate measurement tools for temperature measurement, resistance measurement, and power measurement will also greatly improve the accuracy of the measurement.

6 Reference

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