Heat Transfer

Conduction

Introduction

Conduction is the transfer of heat through solid materials. Thermal conductivity is the measure of how fast a material conducts heat. The opposite of conductivity is resistivity, or insulating value. Metals, like aluminum or iron, conduct very well, that is, they are good conductors and poor insulators. Materials with air trapped in them, like wool, bedding, or Styrofoam, conduct very slowly; they are good insulators. Most solid materials, like wood, plastic, or stone, are somewhere in between.

How does heat flow through solids?

Factors that affect heat conduction

The rate of heat transferred by conduction depends on the conductivity, the thickness, and the area of the material. It is also directly proportional to the temperature difference across the material. Mathematically, it looks like this:

$$\Delta Q/\Delta t = -kA(\Delta T/L)$$

$(\Delta Q/\Delta t)$ **= the rate of heat conduction (kJ/s)**
ΔT **= temperature difference across the material**
L **= thickness of the layer (m)**
A **= area of the material (m²)**
k **= thermal conductivity of the material per unit thickness (kJ/m/s/°C)**

The symbol Δ (delta) means "change in." It could also be written as follows:

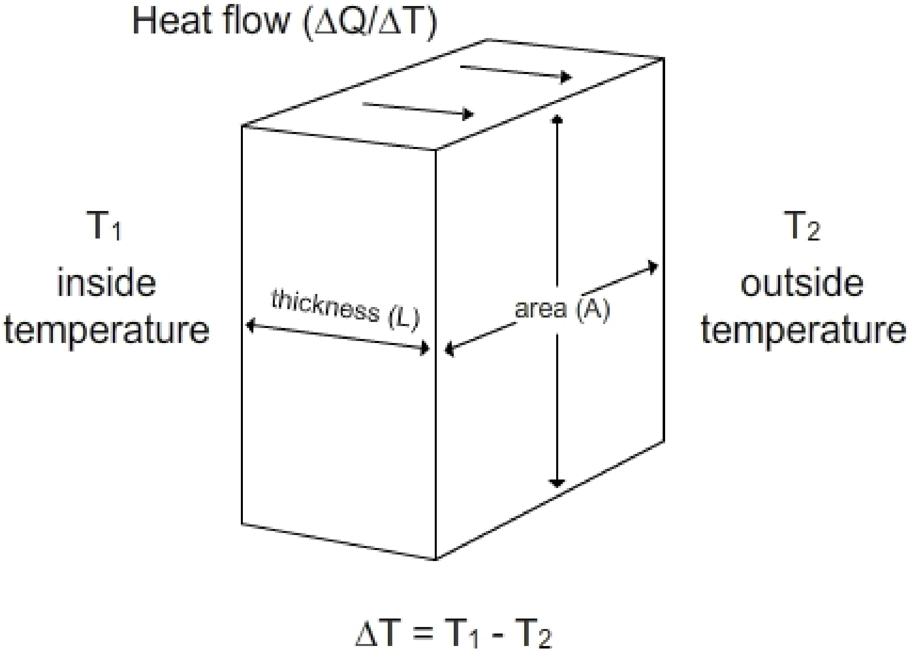
$$\Delta Q/\Delta t = (Q_2 - Q_1)/(t_2 - t_1)$$

$$\Delta T = (T_2 - T_1)$$

Note that $\Delta Q/\Delta t$ is the *rate* of heat flow by conduction, that is, how fast it flows through the material. The *amount* of heat flow is ΔQ .

Rate of heat flow is in units of power (Joules per second). Amount of heat is in units of energy (Joules). See th end of this activity for a review of the difference between power and energy.

Note: This is one section of the "Science of Heat Transfer" chapter of the Engineering Energy Efficiency Project. See: http://concord.org/engineering



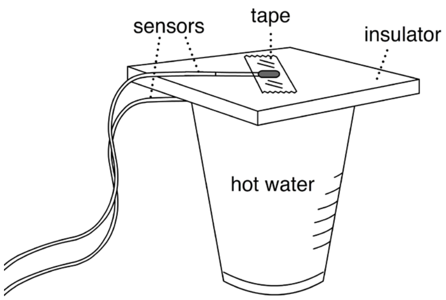
Factors that affect heat conduction through a solid material.

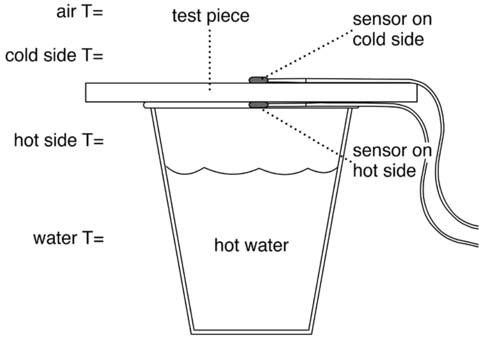
Conductivity of different materials

In this experiment you will measure the relative conductivity of various materials by placing them over a cup of hot water and measuring the temperatures on both sides.

Procedure & data collection

1. Pick a test material from the available collection of sample squares.
2. Attach the two temperature sensors to the computer.
3. Fill a foam cup with very hot water and bring it to your work station.
4. Measure the room temperature and the hot water temperature by putting one of the sensors first in air and then in the water in the cup. Record them in Table 1 below.
5. Start data collection. Tape a temperature sensor to each side of a piece of material. The tape should cover the sensor and hold it tightly to the surface.



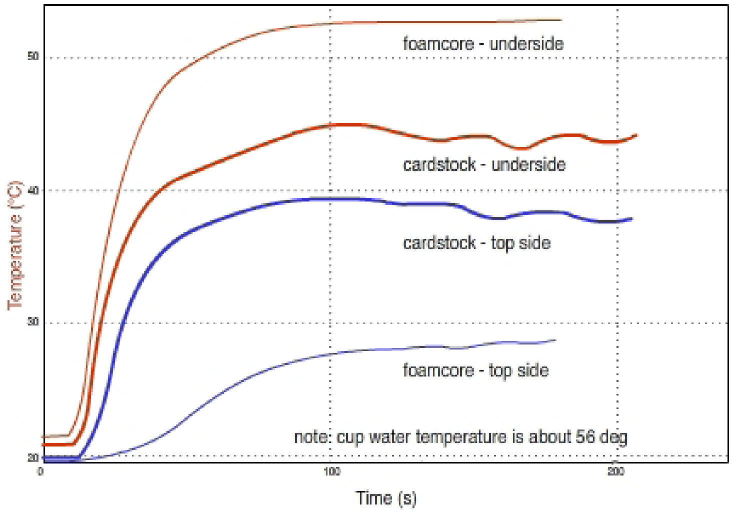


6. Place the material on top of the cup and hold it firmly in place, touching only the edges.
7. Observe the temperature graphs. After they stop changing very quickly (about three minutes), stop data collection and scale the graph.
8. Write down the steady state temperatures in Table 1.

Tools & materials

- Two fast-response temperature sensors (for example, the Vernier surface temperature sensor STS-BTA)
- Computer or other graphing interface for temperature sensors
- Hot tap water
- Styrofoam cups
- Squares of different rigid materials (aluminum, cardstock, cardboard, foamcore) large enough to cover the cup
- Clear tape

9. Pick another material and repeat steps 5-8. Record all the data as different runs. (To do this in the Vernier software, click on the "store" icon before starting to collect a new dataset.) Here's an example. The thicker lines are the current experiment, and the thinner lines are a previous run.



10. Save your data file.

Conductivity of materials

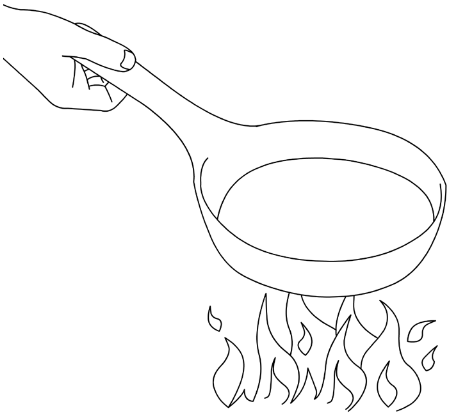
Material	Water temperature	Air temperature	Inside surface temperature	Outside surface temperature	Difference across material
Initial conditions					
Aluminum					
Cardstock					
Foamcore					

Results

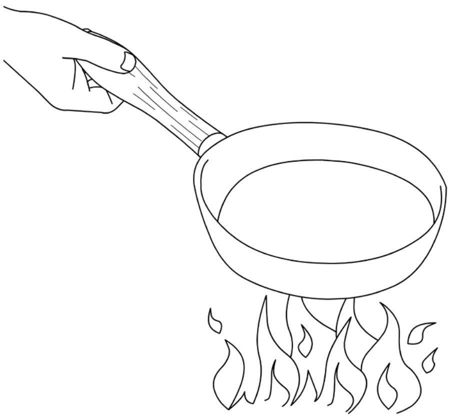
How is the temperature difference related to the thermal conductivity (k)? Explain your reasoning for this.

Analysis

The diagrams below show a frying pan over a fire. In each case, indicate which variable in the equation is changed from one drawing to the other, and whether the heat reaching your hand is great for drawing A or drawing B.



A. metal handle

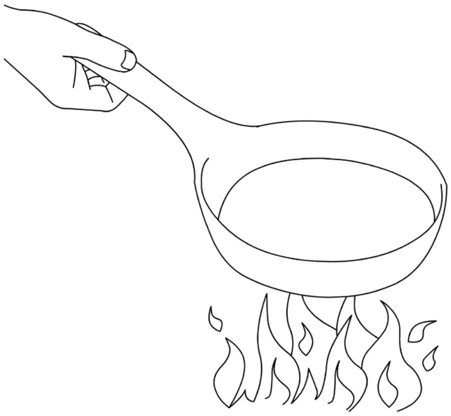


B. rubber handle

In which case, A or B, will the rate of heat reaching your hand be greater?

Which variable in the equation is being changed?

Describe an everyday situation where you have directly experienced the difference in conductivity between two materials.

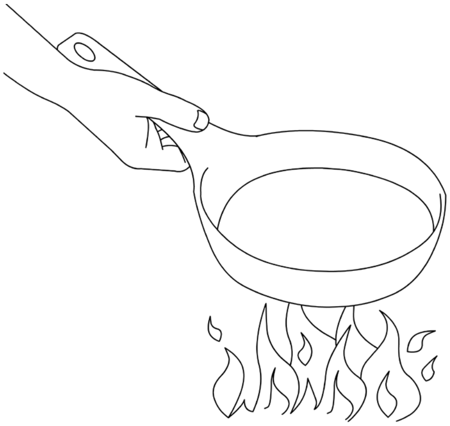


A. hand farther up the handle

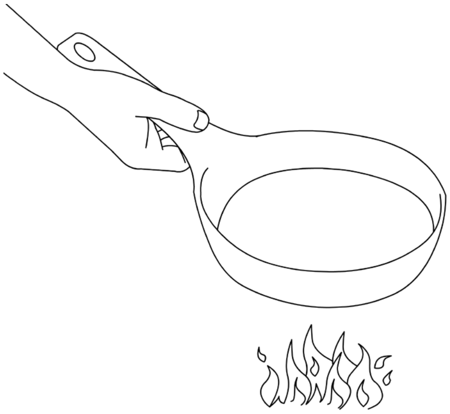
B. hand closer to the pan

In which case, A or B, will the rate of heat reaching your hand be greater?

Which variable in the equation is being changed?



A. more intense heat source



B. less intense heat source

In which case, A or B, will the rate of heat reaching your hand be greater?

Which variable in the equation is being changed?

Connection to buildings

Background

In the building trades, the rate of heat loss is called conductivity (U), which is the same as k, seen on page 31. The most common measure of conductivity is its inverse: resistance to heat flow, called R or R-value.

R (thermal resistivity) = 1 / U (thermal conductivity)

The greater the value of R, the more slowly heat is lost. Doubling R-value means the rate of heat loss is cut in half.

The American building trades don't use metric units. For instance, heat flow is measured in British Thermal Units (BTU) per hour, instead of kilojoules per second. Temperatures are in Fahrenheit rather than Celsius. Thickness is in inches, and area is in feet instead of meters.

To do real calculations on a building, you must get used to doing lots of conversions of units! This project will focus on the relative behavior of different materials, rather than exact calculations.

R can be given per inch of material or for the whole assembly. For example, many common insulating materials have an R-value of 3 to 5 per inch, in standard American units. Fiberglass in a 5 ½" wood frame wall adds up to about R-20. Insulation in ceilings and roofs, where there's more room for insulation, is commonly R-30 to R-40.

Windows typically have the lowest R-value in the building envelope: R-1 for single glazed, R-2 for double glazed, and R-3 or 4 for triple or specially treated glazing. So the typical wall is five to ten times as insulating as the typical window. But there is five to ten times as much wall area as window area, so the two elements contribute equally to the total heat loss, roughly speaking.

Note that the true insulating value of a wall or ceiling depends very much on the quality of workmanship. Gaps and voids can radically reduce the nominal R-value.

Material	Approximate R-value in US units
2x4 wall with insulation	12
2x6 wall with insulation	20
12” of attic insulation	45
12” masonry or concrete foundation wall	2
Single sheet of glass	1
Insulated glass	2
High-performance insulated glass	3
Insulated door	5

Masonry is surprising. It has a high thermal heat capacity, but its R-value is low. That is, it stores a lot of heat, but it also conducts heat well. An 8” masonry or concrete wall has only as much R-value as a double-glazed window (about R = 2)!

Describe the advantages of a well-insulated house.

Recall that heat loss is proportional to both the thermal conductivity and the area of a surface such as a wall. If a house had ten times as much wall area as it had window area, and the wall was ten times as insulating, what would be the relative heat loss from wall and window?

Why do you think it's common to add so much insulation in the attic (see preceding chart)?