Soda cans aid teaching of thermal conductivity

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HEAT

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There are topics in basic physics for which we can find plenty of simple experiments (for example, centre of gravity) and there are topics, such as heat conduction, that seem to be difficult for experiments. You can find descriptions of some evergreen experiments, such as how to demonstrate poor thermal conductivity of water (for example, see [1]) or reports about set-ups for measuring thermal conductivity [2, 3], but the list is not long. Hopefully the simple experiment described in this article will add another contribution to the list.

When we teach about heat conduction through a

Figure 1. *Old demonstration experiment for comparing thermal conductivities of different metals (from the collection of Jurij Vega High School, Idrija, Slovenia).*

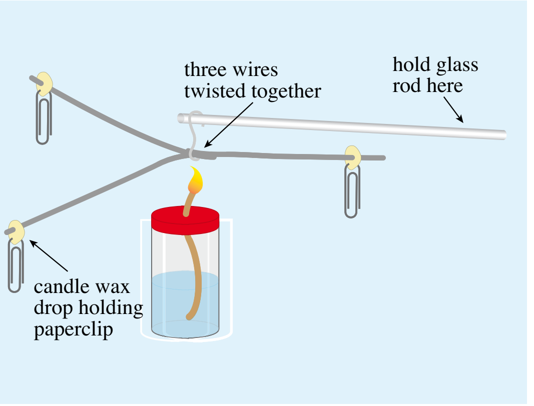

Figure 2. *A suggestion for a simple experiment for comparing thermal conductivities of three metal bars (adapted from [4]).*

system we say that heat flow is proportional to the temperature difference across the system $T_H–T_L$, proportional to the area of the conducting path cross-section S, and inversely proportional to the thickness of the conductor d:

$$P = \lambda \frac{S(T_H - T_L)}{d}.$$

The coefficient λ depends on the material and is called thermal conductivity. What we often forget to stress is that the formula describes the stationary situation meaning that temperatures T_H and T_L do not change with time. And the stationary condition is often violated in the experiments that we show. Experiments that demonstrate differences in thermal conductivities of various metals often employ metal bars and wax. One set of ends of the bars is kept at common high temperature (for example, dipped in hot water), while other ends are covered with wax and left in the air. An old experiment of this type is shown in figure 1 and a suggestion for a homemade version of the simple experiment [4] is shown in figure 2.

The point of these experiments is to observe on which metal bar wax will start to melt first, second and third, and conclude that thermal conductivities of the metals in question are ordered in the same sequence from the highest to the lowest. Although the conclusion is qualitatively correct, strictly speaking these experiments are not consistent with Newton's equation given above.

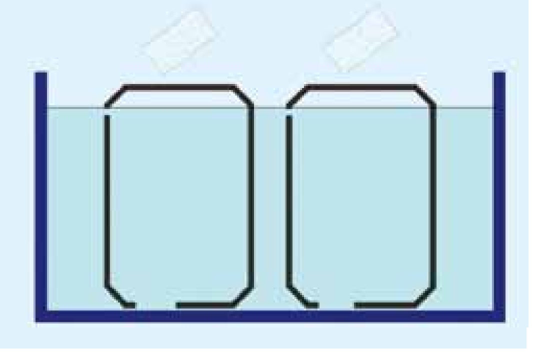

Figure 3. *A sketch of the experimental set-up.*

There are at least two problems with these experiments.

1. For the set-ups that are usually used, the temperature distribution in metal bars does not reach steady state during the whole experiment.
2. Wax does not melt at a particular temperature (like ice) but in a temperature range. The temperature of the waxed end is thus ill defined even after a longer time.

A simple experiment that is more consistent with the content that we teach can be made using two empty soda cans, two equal ice cubes and hot water. I will describe the experiment as seen by students first and then reveal the explanation of the outcome. The teacher turns two empty soda cans upside down into the hot water. The water is just deep enough to reach the rim of the can's bottom, as shown in figure 3. Before dipping the cans into

Figure 4. *The ice cube on the Pepsi can (right) is melting faster than the ice cube on the Coke can (left). The can bottoms are sprayed black to improve the visibility of the melted ice.*

Figure 5. *Labels on soda cans that indicate the type of metal: aluminium (left) and steel (right). Note that the design of the labels may vary.*

the water the teacher makes several small holes just above the bottom of each can to allow air from the cans to leave. Then the teacher places two equal ice cubes on the cans' concave bottoms.

The ice cubes start to melt immediately but it is soon evident that ice on the Pepsi can melts faster than ice on the Coke can. Figure 4 shows the situation about half a minute after the ice cubes have been placed on the cans (the water temperature was about 60 °C). What are the possible explanations for this surprising outcome?

Maybe the bottom of the Coke can is thinner than that of the Pepsi can? We cut the can bottoms and found out that both had thicknesses of 0.2 mm. Could it be that they are made from different materials? Yes! In our case the Pepsi can is made from aluminium and the Coke can is made from steel coated with a thin layer of tin (a magnet sticks to it). The thermal conductivity of aluminium is about 240 W/mK and that of steel is much lower (between 20 and 40 W/mK). Aluminium alloys typically have a smaller thermal conductivity than pure aluminium but it is still more than twice the thermal conductivity of steel. In some parts of Europe and Asia about half of the cans are made from steel and the rest from aluminium alloy. You can find information about this on the cans (figure 5) or simply take a magnet with you when you go shopping. In the US all cans are made from aluminium, so if you live in America don't forget to bring home a tin can from your next overseas journey.

Why doesn't this experiment have the deficiencies of the experiments mentioned at the beginning? Because the heat capacity of the part of the soda cans above the water is very small, steady-state temperature distribution is formed almost immediately after the ice cubes are placed on the cans. Because ice has a well-defined melting temperature, and the mass of the water is much larger than the masses of the cans and ice, the temperature of the hot and cold side of the system (in our case this is the can bottom) remains constant during the experiment.

And what are the benefits of tin cans? Apparently they are easier to recycle and pose a smaller health risk. So the fact that soda cans may also be connected with health or environmental issues is what makes this even more interesting and relevant from the students' perspective.

References

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[4] Liem T L 1981 *Invitation to Science Inquiry* 2nd edn (Lexington, MA: Ginn Press)

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