# Introducing Specific Heat Through Cooling Curves

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In this note we describe a new laboratory exercise for studying specific heats. A number of useful papers[1–4] dealing with this subject have appeared previously in *TPT*. An interesting feature of the exercise we describe is that it does not require the use of a calorimeter. A room-temperature aluminum specimen is placed in a beaker of hot water. Thermal energy is transferred from the water to the aluminum, causing both to quickly reach the same temperature. Using sufficient care, the familiar conservation of energy equations may be applied to this process in order to estimate the specific heat of the aluminum. During the experiment, the system loses thermal energy to its surroundings. But a careful study of the entire cooling curve for the system allows all of the necessary temperatures to be determined for use in the energy calculations.

## Experimental Procedure

The apparatus consists of an aluminum block, a glass beaker, a hotplate, a pan balance, and a digital thermometer. The experimental procedure is quite simple. First, water is poured into the beaker and its mass $m_W$ is determined. The mass $m_{Al}$ of the aluminum sample is also measured and room temperature $T_R$ is recorded. Using the hotplate, the water is heated to a temperature of about 60°C and then allowed to cool. Water temperature measurements are taken at about one-minute intervals until the temperature has fallen by about 10°C. Then the aluminum block (initially at room temperature) is placed in the water. For a short time the temperature reading will drop much more rapidly. During this short time interval, temperature measurements should be recorded every five seconds. Once the cooling process has returned to a slow decline, the readings may again be made at one-minute intervals. Figure 1 shows a typical cooling curve.

## Data Analysis

When the aluminum block is immersed into the higher-temperature water, a transfer of thermal energy occurs. The resulting energy gain of the aluminum is given by $Q_{Al} = m_{Al} c_{Al}(T^f_S - T^i_{Al})$, where $c_{Al}$ is the specific heat of aluminum, $T^i_{Al}$ is the initial temperature ($T_R$) of the aluminum block, and $T^f_S$ is the temperature of the system after the thermal energy transfer has taken place (see Fig. 1). The corresponding amount of energy lost by the water is given by $Q_W = m_W c_W T_{eff}$, where $c_W$ is the specific heat of water and $T_{eff}$ is the change in temperature of the water due *only* to the thermal energy transferred to the aluminum. Without the presence of the aluminum, the water would have continued to cool (according to Newton's law of cooling), following the upper curve shown in Fig. 1. That curve may be extrapolated over the lower one in order to find $T_{eff}$, the temperature difference between $T^f_S$ and the corresponding point on the extended upper curve.[5]

Now setting $Q_{Al} = Q_W$, we can obtain our estimate of the specific heat of the aluminum.

$$c_{Al} = \frac{m_W c_W \Delta T_{eff}}{m_{Al}(T^f_S - T^i_{Al})} =$$

$$\frac{400.0\text{g} \times 1.00\frac{\text{cal}}{\text{g°C}} \times (51.1\text{°C} - 49.2\text{°C})}{145.1\text{g} \times (49.2\text{°C} - 26.5\text{°C})}$$

$$c_{Al} = 0.23 \pm 0.06\frac{\text{cal}}{\text{g°C}}.$$

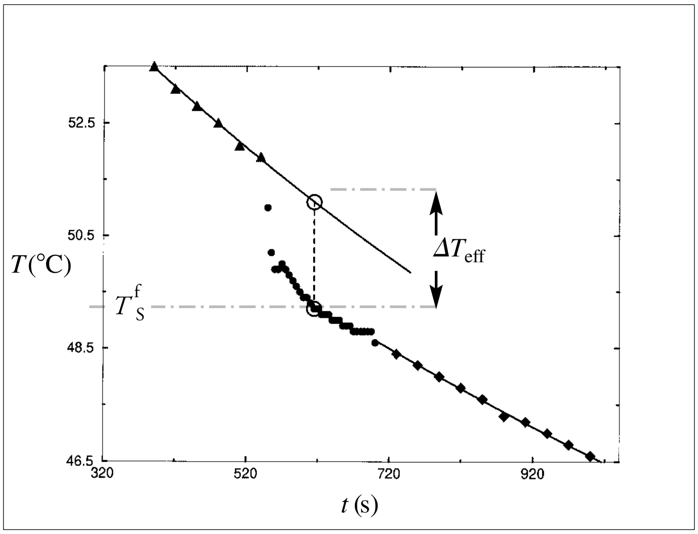


**Fig. 1. Determination of the corrected initial temperature of the water and final temperature of the system. $T_i^S$ = 50.1°C and $T_f^S$ = 49.2°C.**

This value is reasonable considering the simple method used. The "calibration curve" method,[5] while requiring additional time to carry out, takes more accurate account of energy losses to the surroundings. We ignored the mass loss of water due to evaporation during the experiment and also the effect of any transfer of energy from the beaker to the water after the immersion of the aluminum sample.

These effects are excellent points for class discussion, and of course the experiment may be further refined to take them into account.

## Comments

We have found that some care must be taken in choosing the mass of the aluminum sample and the initial temperature of the water. An aluminum sample with a mass on the order of a third of the mass of the water allows good results to be obtained in a reasonable time. If the mass ratio is much smaller than one-third, the rapid transition in cooling curve may be hard to see. If the mass ratio is too high, the temperature changes occur too quickly to measure. Our experiments have also shown that an initial system temperature of approximately 60°C works very well and results in a cooling curve between the aluminum block and the water that is easily measured. If the aluminum is placed in water having a temperature much higher than 60°C, the $T(t)$ curve will have a too-large slope, making temperature measurements difficult.

Finally, we have found that this experiment allows discussions about several concepts, such as specific heat, thermal energy transfer, cooling processes, and exponential decay. It is designed to be an excellent exercise to introduce a discussion of these concepts for students at high school or first-year undergraduate level.

## References

1. James L. Hunt and Tracy L. Tegart, "Measuring the heats of water," *Phys. Teach.* **32**, 545 (Dec. 1994).
2. Ronald F. Gleeson, "A sequel to the PSNS specific heat experiment," *Phys. Teach.* **10**, 399–400 (Oct. 1972).
3. Francisco Glover, "Specific heat capacity— A quantum explanation," *Phys. Teach.* **7**, 149–156 (March 1969).
4. Peter Lindenfeld, "Size effects in conductivity and superconductivity," *Phys. Teach.* **18**, 260–267 (April 1980).
5. A more accurate value of $T_{eff}$ may be obtained by using Fig. 1 in conjunction with a second measured cooling curve. This "calibration" curve is obtained using an identical sample of initially hot water. The sample is allowed to cool undisturbed, i.e., without having the aluminum placed in it. When this second cooling curve is superimposed on the upper portion of the curve in Fig. 1, it extends through the transition region and thus removes the need for any extrapolation. The value of $T_{eff}$ is then the difference between $T^{f}_{S}$ and the corresponding point on the calibration curve.