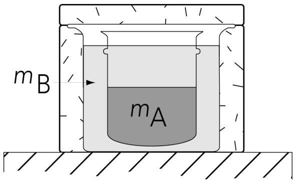

Fig. 16.6. Two vessels of water in thermal contact surrounded by an insulator such as a covered Styrofoam cup.

d. Use the equipment listed above or other available apparatus to test your prediction in part b. This can be done by filling the aluminum tube with a mass, m_A, of hot water. This tube can then be placed in an insulated container with very cold water of mass m_B. This is shown in Figure 16.6. Electronic temperature sensors should be placed in each container of water. Monitoring the temperatures on a real time graph for about 3 minutes should be sufficient. Briefly describe what you did and your results. If possible, you should share your results with others. **Note:** To compensate for the lack of perfect insulation of the system from its surroundings, use about 4 or 5 times as much chilled water in the Styrofoam cup as you have hot water in the aluminum tube.

e. How did your observations agree with your prediction? Is there any evidence of the liquids mixing together or exchanging matter during the thermal interaction? Is there any visible exchange of matter? Explain any new ideas about how the thermal interaction might be causing the temperatures to change.

Parts of any insulated system can be in thermal contact with each other without mixing. If these parts have different temperatures, they will interact until the entire system is at the same temperature. This is a mysterious process, because the *interaction that causes temperature changes in two parts of a system can occur without an exchange of matter*.

You should have noticed from your experiments and those of your classmates that the relative masses of the parts of your thermally isolated system affect the value of the final equilibrium temperature. Thus, the interaction between two parts of a system cannot be explained as a simple temperature change. We need to create a new concept to help us understand warming and cooling processes. Scientists have invented the concept of thermal energy transfer (or heat transfer) to explain this phenomenon.

The use of the noun “heat” is misleading, since using this term to explain temperature changes implies the exchange of a substance between two parts of a system. The word “heat” is actually a sloppy shorthand for an interaction process that often leads to temperature changes. As a reminder that we are dealing with a process rather than a substance, we are going to refer to thermal energy transfer (or sometimes heat transfer) and not simply *heat* for the remainder of this unit.

What is thermal energy transfer? Can it occur without the exchange of matter? In the remainder of this unit we will endeavor to understand more about the nature of thermal energy transfer, to explore the possibility that it is a form of thermal energy exchange, and to quantify the amount of thermal energy or heat transfer occurring in different processes. In the next unit you will explore a model for explaining thermal energy exchange (or so-called heat transfer processes) on an atomic level.

16.7. COOLING RATES

Before exploring quantitative aspects of thermal energy exchange (heat transfer) and its nature in the next sections, let’s study the rate at which warming and cooling take place under different conditions.

We all know that a cup of hot water will eventually cool down in a room while a cup of ice water will warm up. What is the final temperature of warm water in a room? What does the rate at which the temperature of an object changes depend on? Expressed mathematically, we are asking the question: What does the transfer rate, R, given by the derivative of the temperature, T, with respect to time, t, depend on?

$$R = \frac{dT}{dt} \tag{16.1}$$

Let’s do a thought experiment! Imagine that you transfer thermal energy to any kind of liquid (water, syrup, mercury, antifreeze, and so on) and place it in any type of container. Suppose that you have a large, well-insulated room that can be maintained at any reasonable temperature. Thus, you could chill the room to 0°C (brrr) or warm it up to 35°C (phew!).

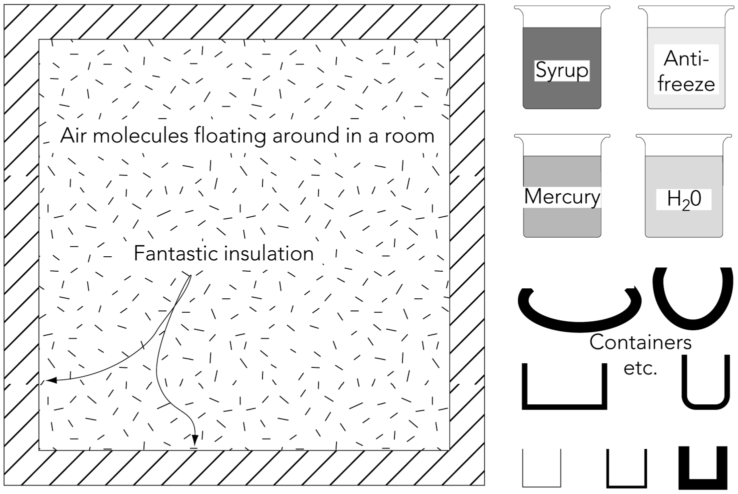

Fig. 16.7. Types of containers and liquids that might be used in experiments to measure cooling rates in an insulated room.

16.7.1. Activity: Predicting Relative Cooling Rates

a. If a small amount of a substance that is at 50°C is placed in a large insulated room, what will the final temperature of the substance be? Will thermal energy transfer to the room take place? Will the room temperature go up? Explain your answer on the basis of your predictions and observations in Activity 16.6.1 parts b. and c.

b. List at least four or five variables that the rate of cooling of an object in a large room might depend on.

c. Describe a situation in which you expect the initial cooling rate of a given object to be rapid and one in which the initial cooling rate might be slow. **Note:** The *initial cooling rate* is the change in temperature per second at first and not the total time it takes something to cool.

Does Container Material Effect Cooling Rate?

One variable that the cooling rate of a liquid might depend on is the material that the walls of the container are made of. In order to explore the effect of the container, you can use the following equipment:

- 1 computer data acquisition system
- 1 temperature sensor (calibrated)
- 1 thin-walled aluminum tube (approx. 1.5” outer dia. × 3.25” high)
- 1 plastic bottle, 2 oz. (approx. 1.5” outer dia. × 3.25” high)
- 1 rubber stopper (no holes, for tube bottom)
- 1 rubber stopper (one hole, for tube lid)
- 1 rubber stopper (one hole, for bottle lid)
- 2 Styrofoam cups
- 1 vat (to prevent spilling)
- crushed ice

Recommended Group Size:	4	Interactive Demo OK?:	N

16.7.2. Activity: Exploring Cooling Rates

a. Suppose you placed equal masses of hot tap water into the plastic bottle and aluminum tube. If each container was immersed in a mixture of ice and water, which container would allow the water to cool faster?

b. Set your temperature sensor to monitor the cooling of each vessel of water for about 4 minutes (or use the experiment file L160702). Set your data rate to about 1 data point per 5 seconds or you will have an overwhelming amount of data. You can immerse each can in a large cup filled with ice and water. *Be sure to shake or stir the liquid in its container during the entire cooling period*. Affix a printout of an overlay graph of your two cooling curves in the space that follows. **Note:** Transfer your temperature data to a spreadsheet and *save it* as you may need it for homework.

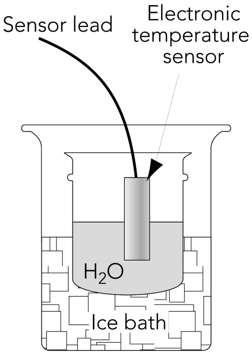

Fig. 16.8. Setup for measuring the cooling rate of water electronically.

c. Was your prediction correct? Explain.

Note: In the situation you just studied, the time rate of decrease in temperature of an object is usually proportional to the temperature difference between the object and its surroundings at each time as it cools. This is known as *Newton's Law of Cooling*. It can be shown mathematically that the dependence of the temperature, T, of an object as a function of elapsed time, t, is given by:

$$T(t) = (T_i - T_s)e^{-\alpha t} + T_s$$

where T_s is the temperature of the surroundings,
T_i is the initial temperature of the object,
and α is the cooling constant, which depends on a number of factors for a given system. It has dimensions of inverse time.